

THE IMPERIAL FORMATION, NORTHEASTERN
MACKENZIE MOUNTAINS, N.W.T.

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BARRY PHILLIP ROBBINS

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THE IMPERIAL FORMATION, NORTHEASTERN
MACKENZIE MOUNTAINS, N.W.T.

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
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by

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ABSTRACT

Provenance, depositional environment and paleoecology of the Imperial formation were determined by means of a petrological and palaeontological study of four sections in the northeastern Mackenzie Mountains.

The principal source for these rocks was sedimentary and low-rank metamorphic terrain lying to the west or northwest of the report area, probably in the northern Yukon. The Imperial formation is entirely marine and was deposited in a warm, shallow sea. Terrestrial organic material indicates the presence of land at some intermediate distance to the west or northwest.

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Frontispiece



View of the middle sandstone-shale unit of the Imperial formation on the Carcajou River, Northwest Territories. Looking northeast from the Carcajou River.



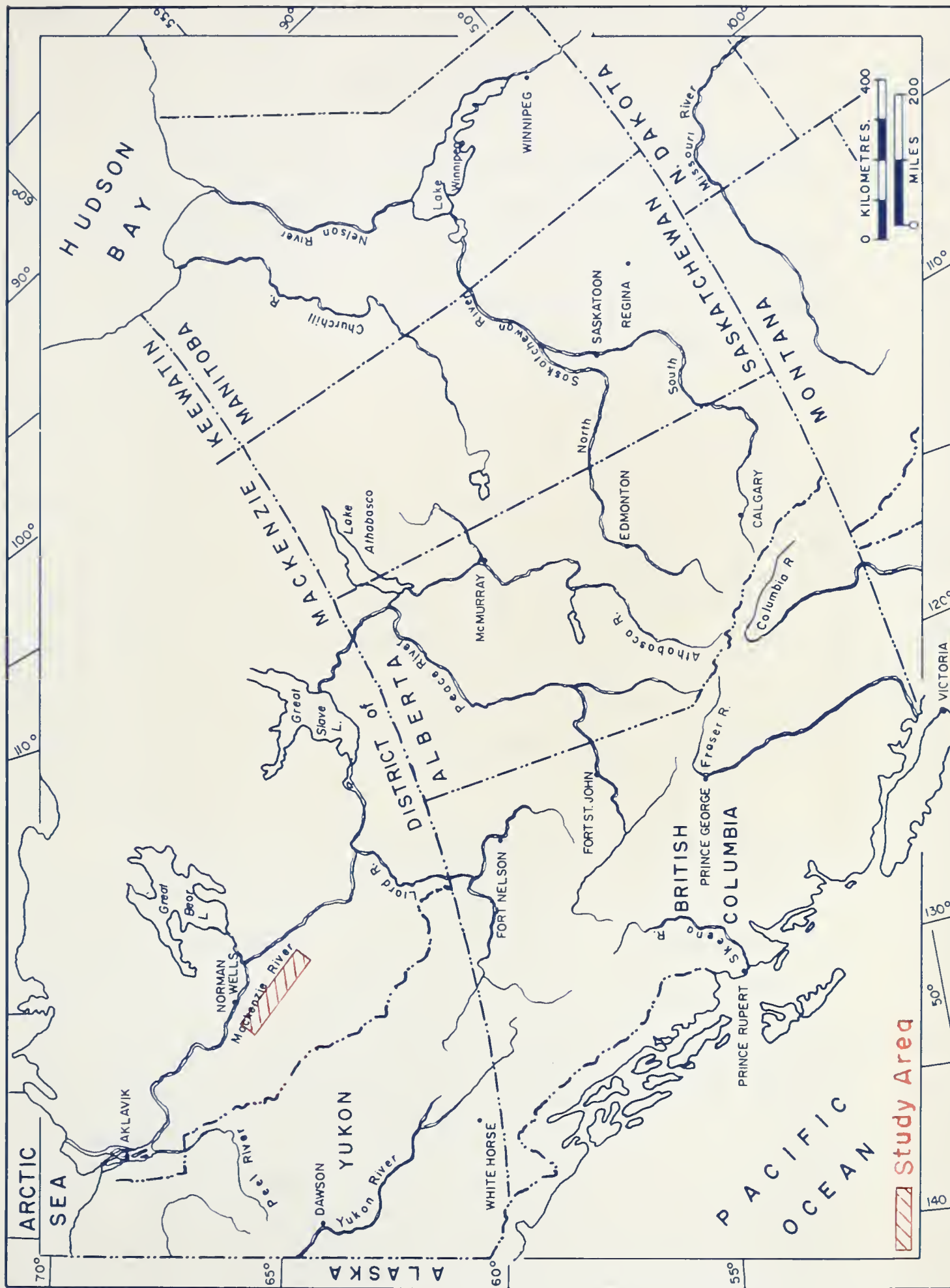
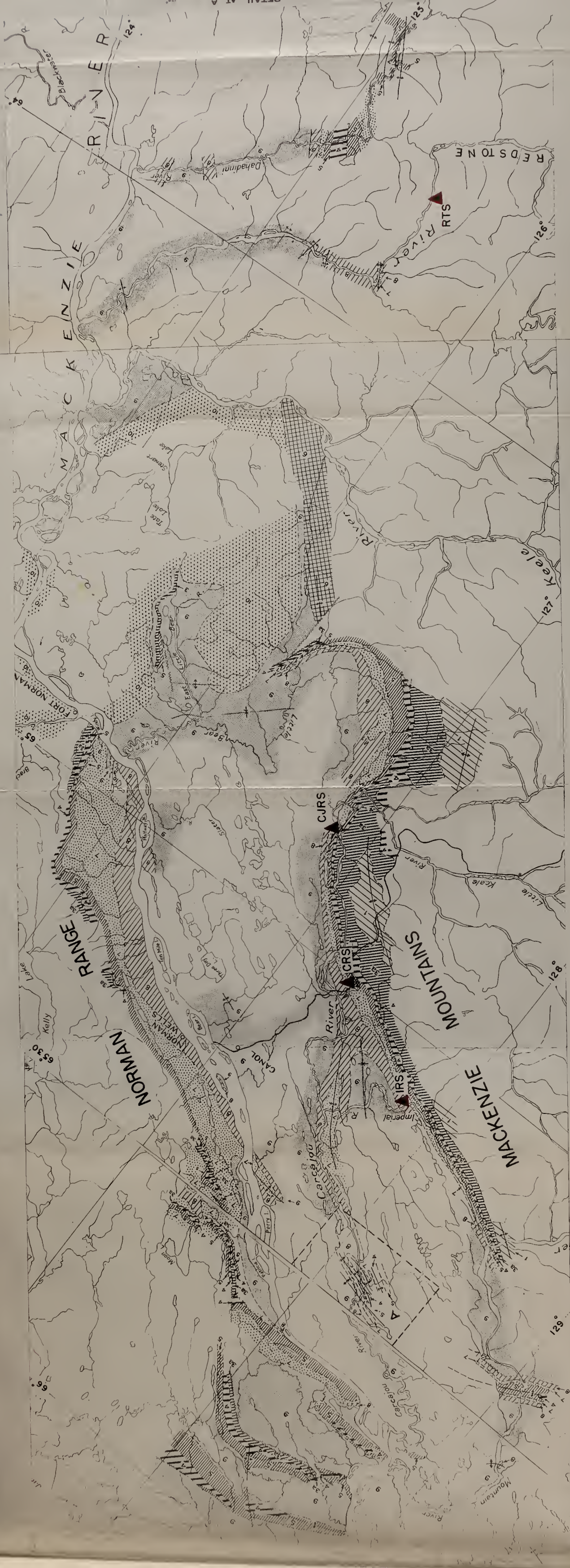


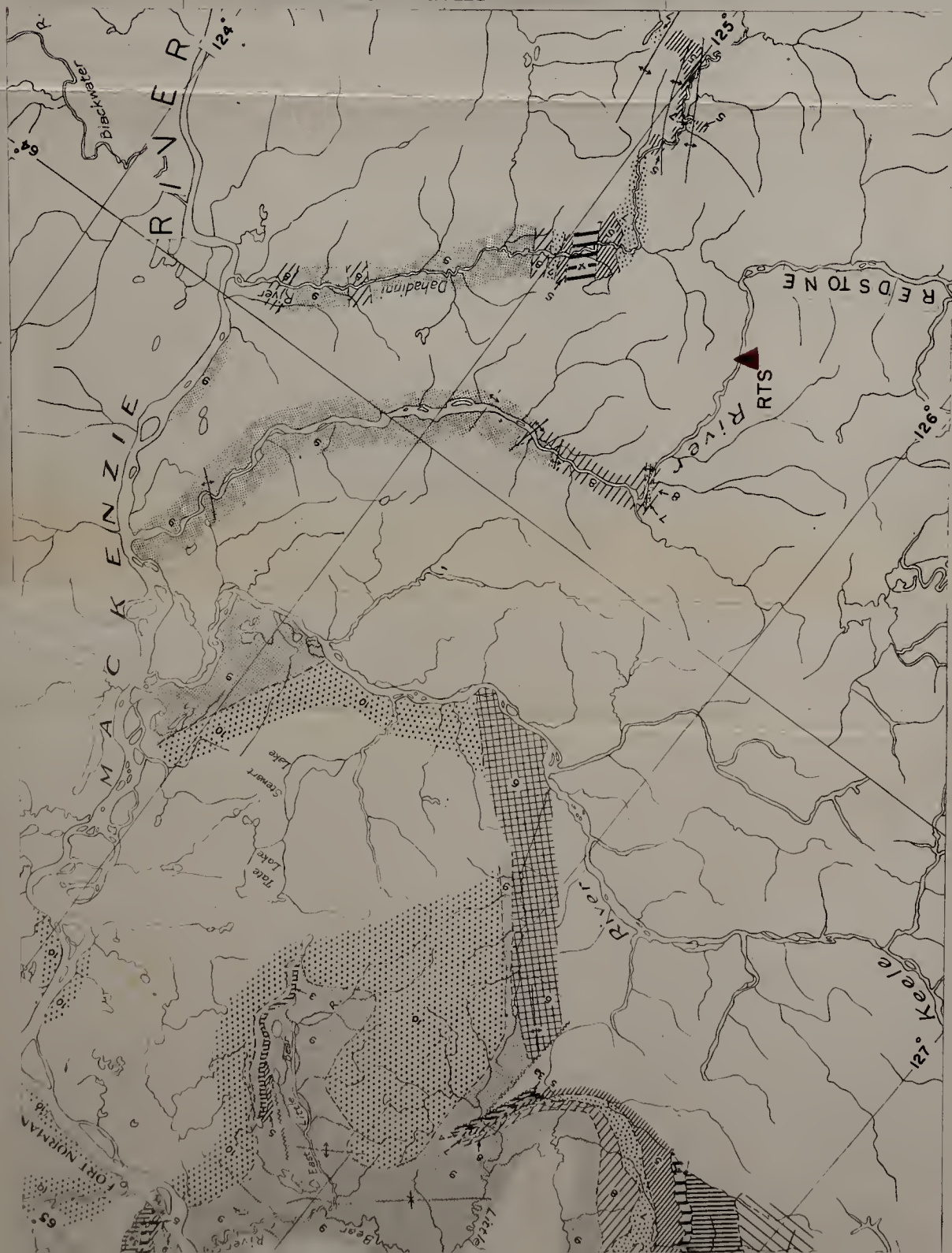
Figure 1 Index Map of Western Canada

Mountains. All exposures studied were located along the banks of major rivers or tributaries to major rivers as only in these areas do good outcrops occur.

Late Devonian strata were measured, described and sampled at four principle localities along the flank of the Mackenzie Mountains south, southeast and southwest of the settlement of Norman Wells on the Mackenzie River. The four sections studied are located on or adjacent to the banks of three major rivers within this area; Imperial River, Carcajou River and Redstone River. Of these four sections, only the Imperial River section (IRS, fig. 2) has been previously described in detail (Laudon, 1950). Although the Carcajou River section (CJRS, fig. 2) and the Canol Road section (CRS, fig. 2) are represented on the map accompanying the Canol Investigations (Hume and Link, 1945) no reference could be found to these particular localities in the text. The section measured on a tributary of the Redstone River (RTS, fig. 2) is not believed to have been described in the literature previously.

The purpose of this investigation was to try to determine the provenance, depositional environment, and paleoecology of the Imperial formation. Information concerning these subjects was obtained by means of a petrological study including thin section study, heavy mineral analysis, and clay analysis, plus a paleontological study of both micro and macro fossils undertaken in order to determine the paleoecology.





History of the Formational Name

The Imperial formation was originally named Bosworth formation by Kindle and Bosworth in 1921. The same beds were referred to as the Camp Creek series by Bosworth in 1921. Kindle in 1936 renamed the formation "Carcajou Mountain Beds" because he discovered that the name Bosworth had previously been used as a formation name by Walcott (1908) for Cambrian strata in the Field area of British Columbia. Kindle suggested that the type section should be on the edge of Carcajou Ridge 43 miles below Bosworth Creek. During the Canol Project a more complete and thicker section than that of Carcajou Ridge was measured by Laudon (Hume and Link, 1945) on the northeast flank of Imperial Mountain Range on Imperial River. Link (Hume and Link, 1945) suggested that this become the type section, and that the unit be named the Imperial formation.

Laudon (Hume and Link, 1945) included the upper non-bituminous part of the Fort Creek shales in the Imperial formation because the division between these and the bituminous shales on which they rest is relatively sharp. Hume (Hume and Link, 1945; Hume, 1954) placed the lower boundary of the Imperial formation at the base of the first "heavy" sandstone bed or in beds that carry the distinctive Spirifer disjunctus fauna. Martin (1959) has observed the non-bituminous shales of the Fort Creek formation to grade laterally into sandstone indistinguishable from sandstones of the Imperial formation. Laudon (Hume and Link, 1945) from his work on the type section has observed that non-bituminous shales of the upper Fort

Creek contain some sandstone and grade upwards into the Imperial formation. As the dominant lithology of the Imperial formation is shale not markedly different from that of the upper non-bituminous Fort Creek shales the writer feels that this upper, non-bituminous shale unit should be a part of the Imperial formation. On this basis plus the presence of a fossil spore assemblage collected, by the writer, from all shales above the true, black, bituminous Fort Creek shales, the lower boundary of the Imperial formation is placed at the last occurrence of black, bituminous Fort Creek shales.

STRATIGRAPHY

Thickness and Distribution

The type section of the Imperial formation on Imperial river as measured by Laudon (Hume and Link, 1945) is 2,349 feet thick. This thickness includes 361 feet of the non-bituminous shale not included in the Imperial formation by Hume and Link (1945) or by Hume (1954). The Imperial River section described in this report is not the type section but is located 5 to 8 miles southwest and upstream from the type section. Laudon (1950) measured a total of 1900 feet of Imperial formation as compared to 1718 feet measured by the writer. As this section is not completely exposed the writer believes there is a total formational thickness slightly in excess of 2,000 feet in this area.

Variation in thickness of the Imperial formation is quite marked within the report area, due to pre-Cretaceous erosion. In the drilling of the Norman Wells oil field the Imperial formation was found to be from 437 to 700 feet thick (Boggs, in Hume and Link, 1945). A total thickness of 1,427 feet of Imperial formation was measured by the writer on the Carcajou River with neither the top nor the bottom of the formation exposed. This thickness compares favorably with those of Nauss (Hume and Link, 1945) who measured from 1,420 to 1,690 feet of section in the upper Carcajou River area.

In the Redstone River section 1,761 feet of strata believed to be equivalent to the Imperial formation were measured.

The upper contact with Cretaceous strata is not present here and the lower beds are gradational into Fort Creek shales. This lower gradational contact of the Imperial formation is noted by Hancock (Hume and Link, 1945) at a section studied on the Redstone River. Hancock measured 1,500 feet of bituminous and non-bituminous Fort Creek shale at this locality as compared with 2,089 feet measured by the writer at RTS. Folding and minor faulting are responsible for part of the abnormally thick sequence of Fort Creek shale present at RTS. The lower boundary of the formation was placed by the writer on the basis of a slight lithologic change and so the thickness of the formation in this area is somewhat doubtful.

The regional distribution of the Imperial formation is not as extensive as the underlying Fort Creek but the formation and its stratigraphic equivalents are recognized over a large area. In the upper Peel River area Stelck (Hume and Link, 1945) mapped marine and non-marine beds 1,050 feet thick believed to be the equivalent of the Imperial formation. He also measured 250 feet of beds presumed to be equivalents of the upper non-bituminous shales of the Norman Wells area. Martin (1959) reports shales and sandstones with conglomerate in the upper part from the Upper Devonian along the flanks of the southern Richardson Mountains, while west of these mountains the Upper Devonian consists almost entirely of conglomeratic sandstones and pebble conglomerates with thicknesses up to 6,000 feet. Martin considers the Upper Devonian strata from the southern Richardson Mountains westward to be non-marine because of the relative abundance of fossil plants and the absence of marine fossils.

McKinnon (Hume and Link, 1945) has described sandstones and shales as far north as the lower 50 miles of Arctic Red River which he believes are Upper Devonian equivalents of the Imperial formation. To the south of Fort Norman on the Mackenzie River Hancock (Hume and Link, 1945) reports Imperial beds in excess of 920 feet with the lower contact gradational into Fort Creek shales.

Hume (1922) in the North Nahanni-Root River area reports 2,100 to 2,600 feet of limestones and shales similar to those reported by Whittaker (1922) on Trout River, which are equivalent in part to the Upper Devonian Imperial formation at Norman Wells. These beds which contain abundant limestones and bioclastics are correlated with the Hay River limestones of Great Slave Lake but contain beds stratigraphically higher than those of the Hay River section (Whittaker, 1922). The highest Upper Devonian beds of the Trout River and North Nahanni-Root River sections are also stratigraphically higher than any that occur in the Norman Wells area (Hume, 1923).

Lithology

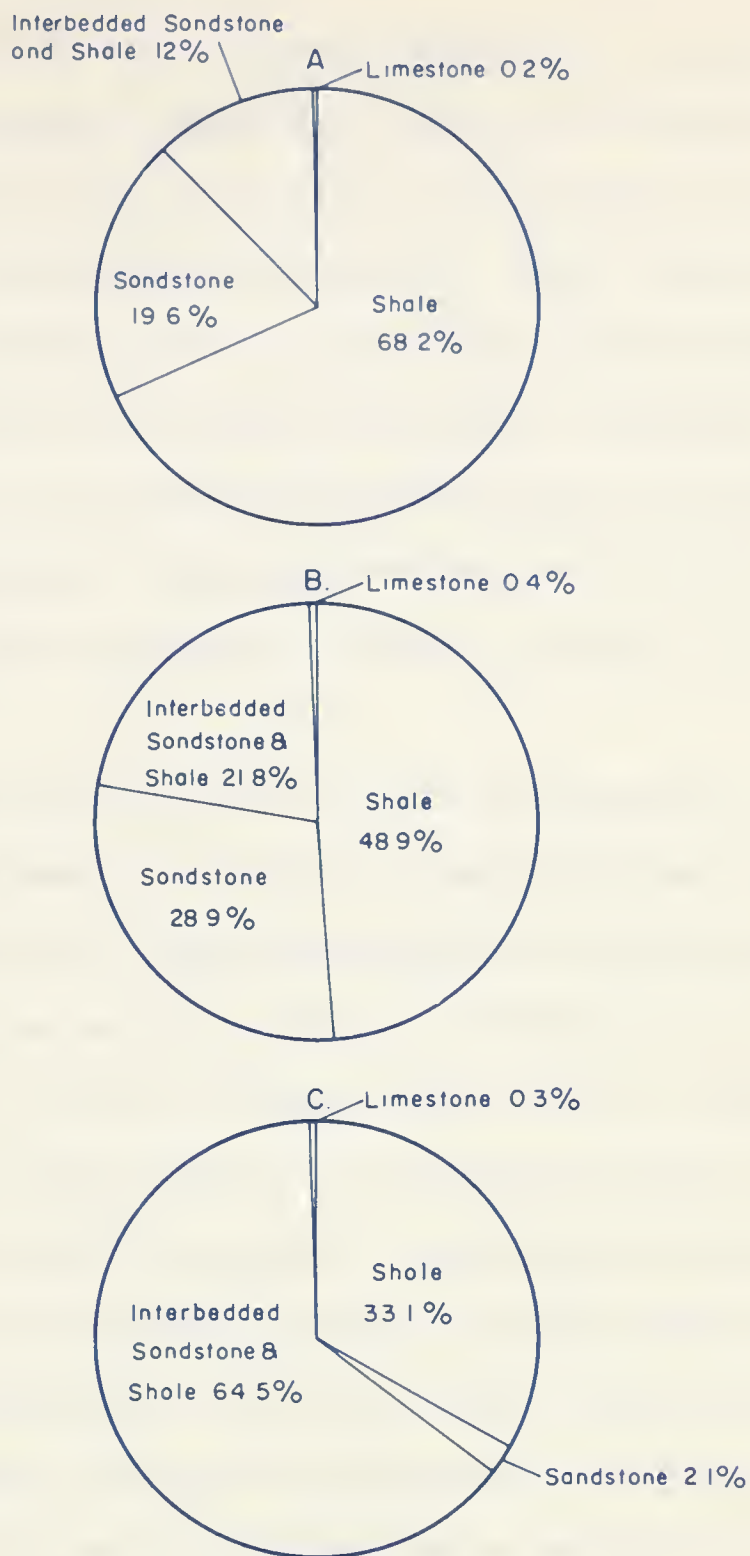
The Imperial formation, within the report area, can be divided into three units; a lower shale unit, a middle sandstone-shale unit with minor organic limestone development and an upper shale unit. Although both sandstones and shales are present within the formation, shale is the dominant lithology. The Imperial formation appears to consist dominantly of sandstones because the middle sandstone-shale unit provides a greater number of exposures. The

upper and lower shale units are commonly not exposed because of their less resistant nature. The thickness of the upper shale unit is extremely variable due to pre-Cretaceous erosion.

The Imperial formation measured on the Imperial River (IRS) was found to be composed of 68 per cent shale, 20 per cent sandstone and 12 per cent interbedded sandstone and shale (fig. 3). This would amount to approximately 75 per cent shale within the measured section. As this section does not have the lower shale unit exposed, it may be assumed that a minimum of 300 feet of shale is missing, thus giving a total of about 80 per cent shale for the entire formation. The same is true of the section measured on the Carcajou River (CJRS). Only the middle sandstone-shale unit is well exposed and a false impression of the lithological proportions is obtained.

Martin (1959) has observed the non-bituminous shales of the Fort Creek formation (here considered the lower shales of the Imperial formation) to grade laterally into sandstones. This would indicate that sandstones are local developments within a shale unit. The writer has observed sandstone beds in the Carcajou River area which extend laterally for over three-quarters of a mile with no indication of thickening or thinning. Although these sandstone beds are laterally fairly extensive attempts at correlating sandstone beds of two sections (IRS and CJRS) over a distance of approximately 38 miles were unsuccessful.

Limestones and biogenic carbonates constitute less than 1 per cent of the total lithology within the report area. These thin carbonates



- A IMPERIAL RIVER SECTION
 B CARCAJOU RIVER SECTION
 C REDSTONE TRIBUTARY SECTION

Fig 3
 CONTRASTING LITHOLOGIC PROPORTIONS OF
 MEASURED IMPERIAL FORMATION SECTIONS

do, however, have widespread development throughout the report area. Carbonate units, separated by relatively equivalent stratigraphic intervals, are present in the three major sections (IRS, CJRS, RTS).

In the southernmost section examined, (RTS), it was noticed that the sandstones become very fine grained and in many instances become siltstones. There is no marked variation in lithologic proportions from the more northwesterly sections but the decrease in grain size is apparent. Tentative correlation of the four measured sections based on lithology is shown in figure 7 (in pocket).

The general lithology of the report area appears to extend westward and northwestward into the physiographic province of the Peel Plateau. Within this latter physiographic province the Imperial formation changes to non-marine argillaceous sandstones and sandy shales (Martin, 1959, fig. 16). Coarse clastics begin to appear in the western portion of this province as shown by Martin who found shales and sandstones with conglomerate in the upper part along the flanks of the Richardson Mountains. West of the Peel Plateau the sediments become increasingly conglomeratic until on Dave Lord Ridge conglomeratic sandstones and pebble conglomerates are commonly present (Martin, 1959). Martin interprets these beds as entirely non-marine because no marine fossils have been found, and fossil plants are common.

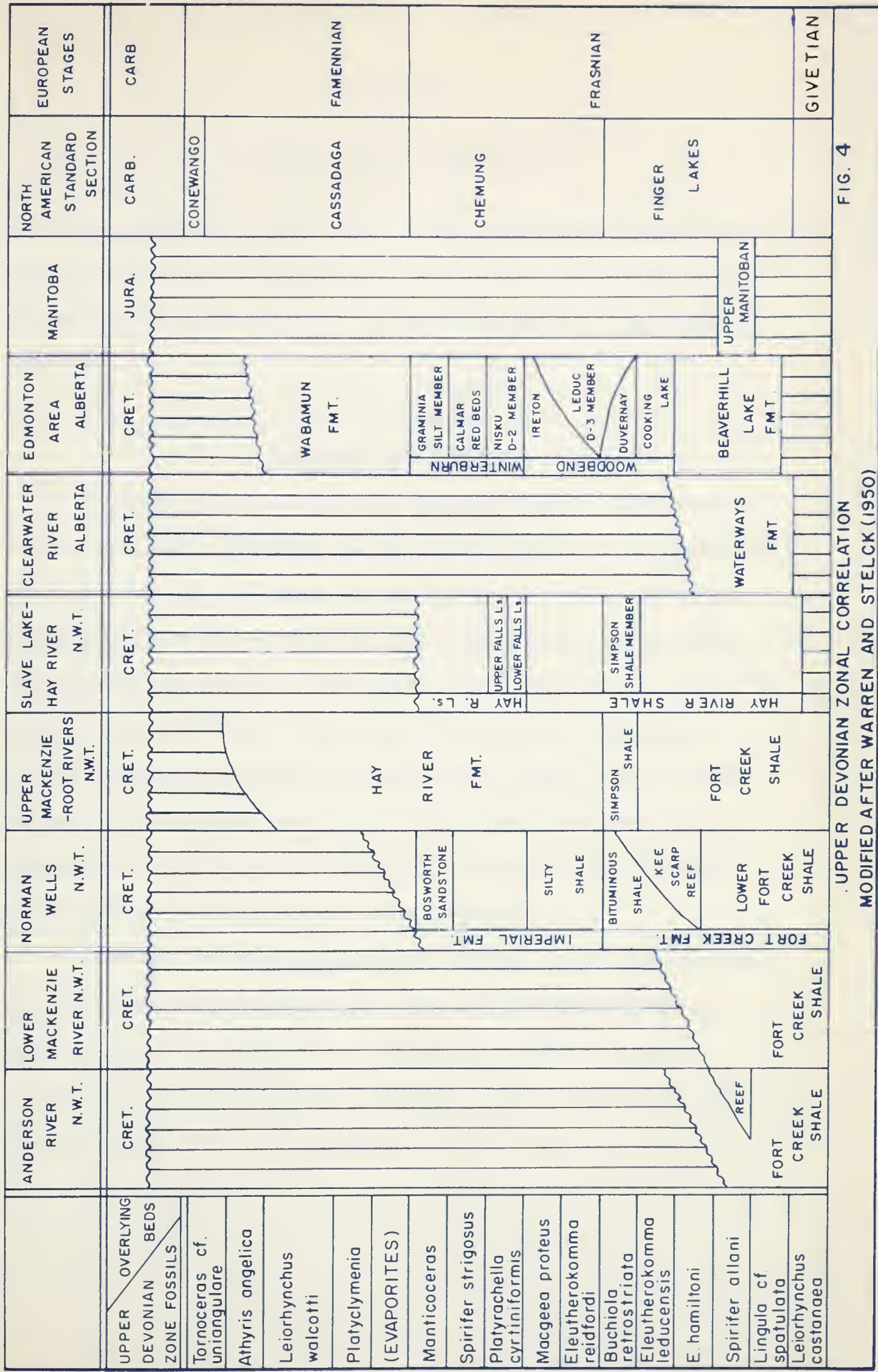
The general lithology within the report area also extends to the south but with a decrease in clastic particle size. As the

distance from the source area increases the seas cleared sufficiently to allow some carbonate development. The development of carbonates within the clastic sequence is well defined in the North Nahanni-Root River area as shown by Hume (1922) who reported 2,100 to 2,600 feet of limestones, bioclastic material and shales from this area. Whittaker (1922) has reported a similar lithology in the Trout River area. Carbonate development within this latter area reached a maximum toward the end of the Late Devonian (Palliser sea).

Age and Correlation

The age of the Imperial formation is unquestionably Late Devonian. Kindle (in Cooper, 1942) has correlated all Late Devonian beds above the Fort Creek shale with the Chemung and lower Cassadaga of the North American type section and with the Frasnian and lowermost Fammenian stage of Europe (fig. 4).

The Imperial formation is correlated with the Hay River limestone of the Great Slave Lake area, and with the Winterburn Group of the Alberta plains. The upper non-bituminous shales of the Fort Creek formation which are here considered a part of the Imperial formation are correlated with the upper Hay River Shales of the Great Slave Lake area and with the Ireton member of the Woodbend Group of the Alberta plains.



UPPER DEVONIAN ZONAL CORRELATION
MODIFIED AFTER WARREN AND STELCK (1950)

PETROGRAPHY

Composition of the Sandstones

A total of twenty-eight thin-sections were examined from three of the sections described in this report. All of the thin-sections are from the middle sandstone-shale unit of the Imperial formation.

Imperial River Section

Eight thin-sections were examined from the Late Devonian at this locality. According to the classification of Pettijohn (1957) the Late Devonian sandstones are predominantly lithic sandstones. These sandstones are all fine to very fine-grained with quartz as the dominant constituent. The quartz grains are angular, subangular, or subrounded and commonly show slight undulatory extinction. Irregular globular and dusty inclusions are common. Quartz never exceeds 50 per cent of the total rock but when considered as a percentage of the essential components (quartz, feldspar, rock fragments), ranges from 86 per cent to 79 per cent.

Chert and microquartzite are present in all thin-sections, ranging from 5 per cent to 11 per cent, but generally constitute approximately 7 per cent of the total rock. Chert and micro-quartzite grains generally show slightly better rounding than quartz grains but are never well rounded and only occasionally rounded.

Feldspar does not exceed 5 per cent of the total rock, but is usually present in the order of 3 per cent to 4 per cent. Thin-sections were exposed to hydrofluoric acid fumes and then immersed in sodium cobaltinitrite in order to stain the potash feldspar present. Plagioclase feldspar slightly exceeds the potash variety but never exceeds 4 per cent and is usually present in the order of 2 per cent to 3 per cent. The plagioclase present commonly shows albite and rarely Carlsbad twinning.

Rock fragments constitute from 1 per cent to 10 per cent of the total rock but generally are present in the order of 7 per cent. Most of these grains are rocks containing abundant micaceous and chloritic material. These grains, because of their size and composition, are very difficult to distinguish from the matrix. Large flat well-rounded shale pebbles are commonly found within the formation oriented with their long axis parallel to the bedding. Pebbles of this nature have been noted in certain beds in fairly large numbers and probably represent reworking of a partially consolidated shale.

Matrix composed of micaceous and chloritic phyllosilicates is common in most of the sandstones. Matrix may comprise 16 per cent of the total rock but is commonly present in the range from 10 per cent to 14 per cent. The matrix is very similar in appearance to argillaceous rock fragments which it surrounds and this may have resulted in an overestimation of matrix at the expense of rock fragments. The high percentage of mica and chlorite in these sandstones is responsible for the green color characteristic of the formation.

Cement present in the sandstones is calcite, hematite or siderite. Hematite may constitute up to 25 per cent of certain sandstones where it occurs both as cement (up to 15 per cent) and as clastic material. Calcite and siderite usually total from 5 per cent to 15 per cent of the rock with calcite the more plentiful; siderite rarely exceeds 5 per cent. Siderite most commonly occurs replacing organic remains and is usually in the form of spherules or elliptical grains. Much of the calcite cement appears to be the result of solution and deposition of original carbonate shell material. This is indicated by the "patchy" nature of the cement throughout many of the beds. The amount of calcite cement present in a sandstone appears to be a function of the amount of carbonate shell material. It was noticed that as the organic content increased in the sandstones the percentage of calcite cement increased correspondingly.

Well developed grains of muscovite, biotite and chlorite, exclusive of the fine-grained material discussed under matrix, are present and constitute from 5 per cent to 7 per cent of the total rock. The biotite present is green, and as it is commonly "bleached" to a pale green color it is extremely difficult to distinguish from chlorite in some orientations.

Organic material occurs commonly in the sandstones of the Imperial formation and locally may comprise as much as 25 per cent of the rock. Siderite and more rarely hematite commonly occur as a replacement of the original calcite shell material.

Authigenic hematite is not as common in the sandstones of the Imperial River section as in those of the other two major sections (CJRS, RTS) but locally may make up as much as 25 per cent of the total rock. When present in these large quantities, visual estimation of percentage of other components is extremely difficult.

Glaucconite, carbonaceous material, and heavy minerals are the common accessory minerals (less than 1 per cent) present within most of the sandstones.

Compaction of the formations is evidenced by the distorted nature of the mica and chlorite present. This may not be entirely due to load compaction, however, as the sediments studied were affected by the tectonic movements responsible for the Mackenzie Mountains. Porosity within the sandstones is very small as a result of cementation, compaction, matrix and the small size of the detrital grains.

Carcajou River Section

Twelve thin-sections were examined from this locality. The dominant rock type present is lithic sandstone. The sandstones of the Carcajou River section are very similar to those described from the Imperial River. Percentage composition of quartz, chert, rock fragments and matrix is similar to IRS with only a small increase in calcite cement. The one characteristic feature of this section is the large amount of hematite in the upper portion of the middle sandstone-shale unit.

Redstone Tributary Section

A total of eight thin-sections were studied from this locality. The rock types present are lithic sandstone and lithic graywacke. The sandstones of this section are characterized by an overall decrease in grain size. Laminations of silt-size material occur commonly and there is an increase in the total amount of matrix present with respect to the other two sections. Total amounts of both organic shell material and cement decrease slightly in this section and as stated previously, one is probably a function of the other.

Cretaceous Sandstones

Two sandstones of the overlying Cretaceous strata were studied for purposes of compositional comparison. They are ortho-quartzite and lithic sandstone with a high percentage of quartz and little or no matrix. The amount of cement is low or absent. Distribution of feldspar and rock fragments is similar to the sandstones of the Imperial formation. These sandstones contain up to 5 per cent glauconite.

Summary

Of the twenty-eight thin-sections examined from the Imperial formation, nineteen are lithic sandstones (fig. 5). Quartz, chert and microquartzite constitute greater than 79 per cent of the essential components and the amount of matrix present is less than 15 per cent. Rock fragments exceed feldspar in all these sandstones. Five of the

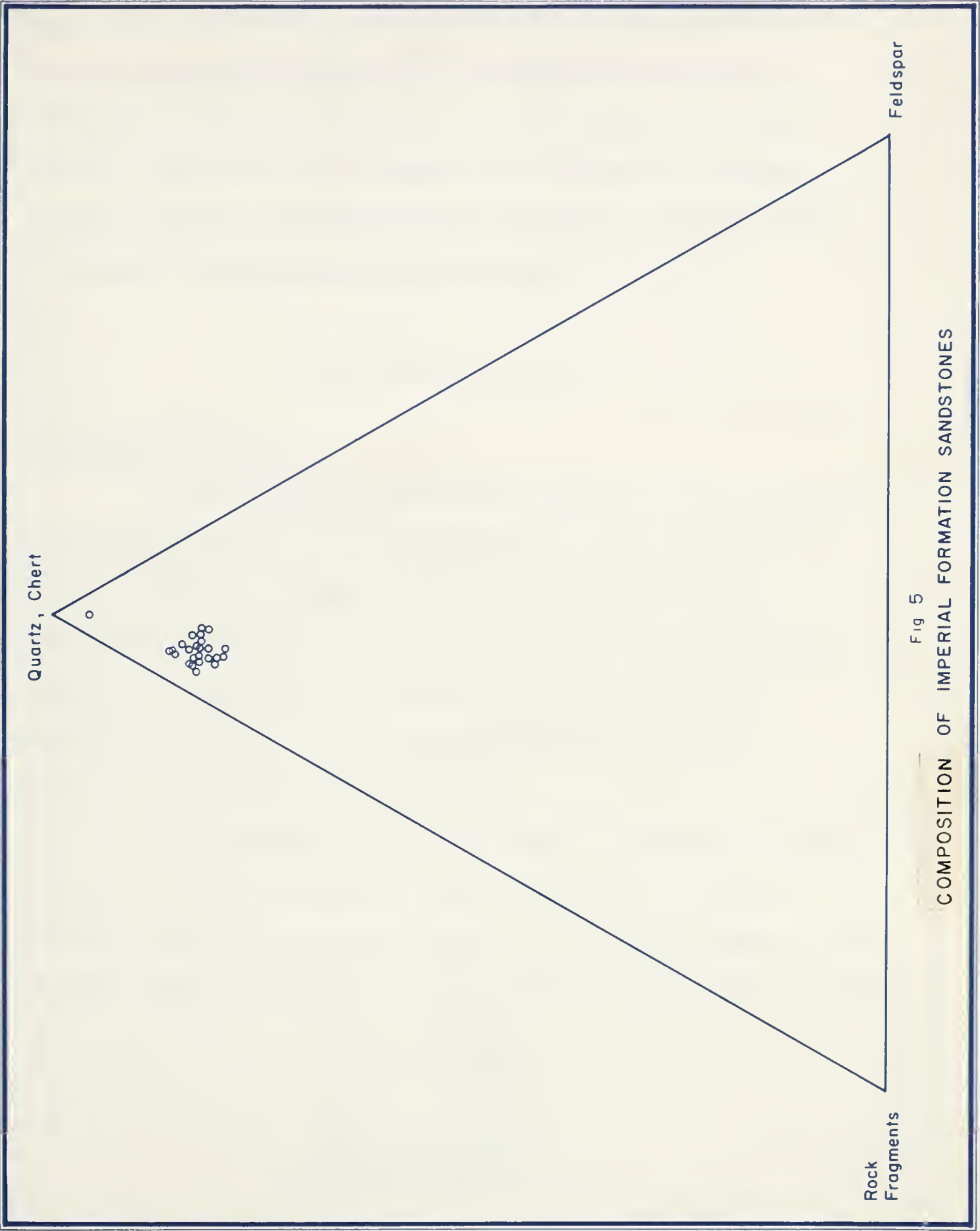


Fig 5
COMPOSITION OF IMPERIAL FORMATION SANDSTONES

samples were classified as lithic graywackes as matrix exceeded 15 per cent. Two of the sandstones contain large quantities of hematite and organic material and are probably best referred to as hematitic bioclastic arenites. Two of the thin-sections were carbonate rocks. These two samples were classified as stromatopoidal limestone and quartzitic biocalcarenite. Photomicrographs of selected thin-sections are shown on plates 7 and 8.

Heavy Accessory Minerals

Preparation of Samples

An investigation of the heavy accessory minerals occurring within the sandstones of the Imperial formation was undertaken on a total of twenty-two samples. Two samples from the overlying Cretaceous sequence were also studied for purposes of compositional comparison. Heavy mineral separations were made using tetrabromoethane (Sp. Gr. 2.9) in a standard separation technique involving the use of a separatory funnel.

Upon completion of the heavy mineral separations the heavy mineral residues were weighed in order to determine the weight percentage contained within each sample. The average weight per cent of heavy minerals in samples from three of the sections are as follows:

IRS - 0.0833%

CJRS - 0.3580%

RTS - 0.2810%

Average - 0.248%

The high values obtained for CJRS and RTS are due to the presence of authigenic hematite and pyrite. These two minerals have coated grains of quartz and other minerals with a specific gravity less than 2.9 causing them to be included with the heavy minerals. The value obtained from IRS is probably very close to the true weight percentage of detrital heavy minerals contained within the Imperial formation. There is no definite increase or decrease in total heavy mineral weights from top of bottom in the various sections. Values vary greatly in CJRS and RTS due to the presence of authigenic hematite and pyrite. Hematite is concentrated near the top of CJRS while distribution in RTS is random

Heavy mineral residues were split, sieved and mounted in aroclor ($n=1.66$) for examination. Sieving of the heavy mineral residues prior to mounting showed that the great majority of the Late Devonian heavy minerals were of silt size (smaller than 0.062 mm.) while those of the Cretaceous were generally of sand size.

All the samples were examined microscopically in both transmitted and reflected light but only thirteen were chosen for statistical counts of heavy minerals.

Interpretation of Heavy Mineral Suite

The following heavy accessory minerals were noted from the Imperial formation. Quantitative determinations are shown in Table 1 and Figure 6.

Non-Opaque

Apatite

Anatase

Biotite and Chlorite

Collophane

Muscovite

Rutile

Siderite

Sphalerite

Spinel

Tourmaline

Zircon

Opaque

Hematite

Leucoxene

Pyrite

The following heavy accessory minerals were noted from the Cretaceous.

Non-Opaque

Anatase

Biotite and Chlorite

Collophane

Garnet

Muscovite

Rutile

Siderite

Spinel

Tourmaline

Zircon

Opaque

Leucoxene

Sample Number	Anatase and Leucocoxene		Apatite	Biotite and Chlorite	Collophane	Garnet		Muscovite	Brown		Yellow	Siderite	Sphalerite	Spinel	Green	Brown	Tourmaline		Zircon		Opagues		Pyrite
						Colorless	Pink		Colorless	Pink							Fc	Fc	Vc	Vc	O	O	
IRS-1	Fa	Vc	Vc	Vc	T	O	O	S	O	Fc	Fc	Vc	Fc	S	Fc	Fc	Fc	Fc	Vc	O	O	T	
IRS-2	Fa	Fc	Fc	Fa	O	O	O	Fc	T	Fc	Fc	R	C	S	C	C	C	C	Vc	O	O	T	
IRS-3	Vc	Fc	Fc	Vc	O	O	O	Vc	T	O	O	Fa	S	T	S	Fc	Fc	Fc	Fc	O	O	S	
IRS-4	Fa	S	S	Fa	Fc	O	O	Fc	Fc	S	S	C	T	S	Fc	S	S	Vc	Vc	O	O	S	
IRS-5	Fa	R	R	Vc	Fc	O	O	C	Fc	Fc	Fc	Fc	T	Fc	S	T	S	Fa	R	O	O	Fc	
IRS-6	C	Vc	Vc	Vc	C	O	O	Fc	O	O	O	S	O	O	C	Fc	Fc	R	R	O	T	A	
IRS-7	C	O	O	S	Fc	A	Fc	O	Fc	T	T	T	O	T	Fc	R	R	Fa	Vc	O	O	O	
CJRS-9	Fa	O	O	C	R	O	O	Fc	T	Fc	S	S	T	R	S	R	C	Vc	R	O	O	Fa	
CJRS-10	Fc	S	S	Vc	O	O	O	Vc	O	Fc	Fc	T	C	S	C	Vc	C	Fa	O	O	O	R	
CJRS-11	Fc	C	C	Fa	T	O	O	Fc	R	S	S	R	O	S	C	Fc	C	Vc	T	T	T	Vc	
CJRS-13	C	Vc	Vc	Vc	T	O	O	Vc	O	S	S	O	S	R	S	S	S	C	C	T	O	A	
* CJRS-15	Fc	S	S	Vc	T	O	O	C	R	Fc	Fc	O	O	T	Fc	S	Fc	Fa	C	Va	O	O	
* CJRS-17	C	C	C	C	Fc	O	O	Fc	S	Fc	Fc	O	O	O	C	Fc	C	Vc	S	Va	O	O	

* Minerals masked by hematite coatings, rough estimates only

Table 1
Relative Abundance of Heavy Minerals

Legend	Percentage	Description	Symbol
	80	Very abundant	Va
	40-80	Abundant	A
	20-40	Fairly abundant	Fa
	10-20	Very common	Vc
	5-10	Common	C
	2-5	Fairly common	Fc
	1-2	Scarce	S
	1/2-1	Rare	R
	1/2	Trace	T
	0	Absent	O

IMPERIAL RIVER SECTION (IRS)

CARCAJOU RIVER SECTION (CJRS)

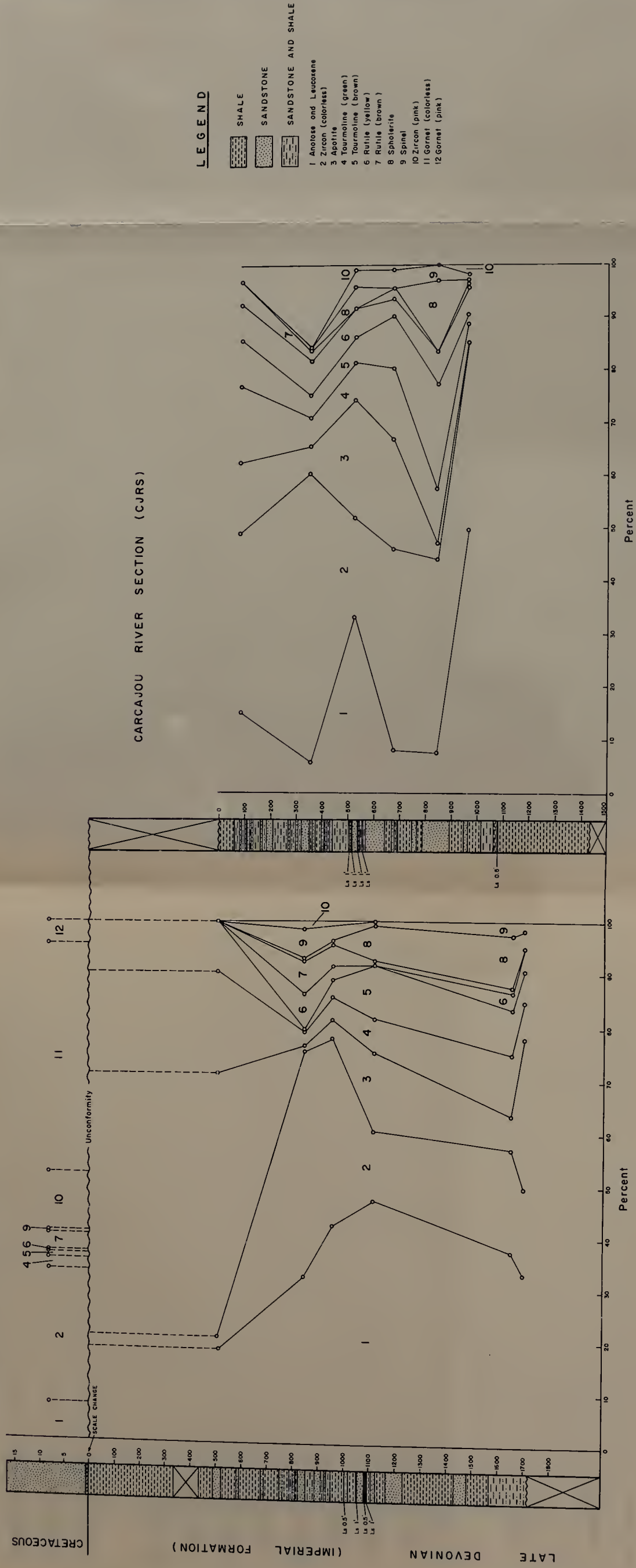


Fig. 6
DISTRIBUTION OF HEAVY MINERALS

The heavy minerals of the Imperial formation vary from anhedral to euhedral and from rounded to angular. The great majority of the heavy mineral grains exhibit some degree of rounding and therefore are probably at least second cycle (i.e. derived from a sedimentary or low rank metamorphic source). Some euhedral, angular heavy mineral grains, exclusive of those formed from in situ alteration or organic decomposition, are present, which suggest the possibility of a minor igneous source.

The heavy mineral suite present within the Imperial formation is a stable suite common to rocks of Late Paleozoic age (Pettijohn, 1957). The absence of the stable mineral garnet may be the result of intrastratal solution or due to removal of the mineral prior to deposition of the Imperial sandstones. The presence of large amounts of anatase and leucoxene with minor brookite probably represents in situ alteration of titaniferous ilmenite as this mineral appears to be absent from the heavy mineral suite. Cementation of the sandstones by calcite, siderite and hematite is extreme in some sandstone beds while in others it is only very slight.

Siderite and more rarely hematite are found replacing original calcite shell material thus indicating a post-depositional age for these materials. Hematite occurs occasionally as oolites or rounded to subrounded grains. These grains represent early replacements or original precipitates. Hematite of this nature is much less common than hematite which occurs as cement of post-depositional age.

Shale Composition

Six shale samples, representative of the shale present in all three of the sedimentary units of the Imperial formation, were studied by means of X-ray analysis for clay mineral content. Mounts of raw powdered shale were prepared with the use of acetone and household cement. X-ray patterns were run on glycolated mounts using Cu radiation, a geiger counter pick-up and Brown recorder.

Results indicate that illite and chlorite were present in all shale samples with the ratios of the two minerals constant throughout. According to Weaver (1958) equal amounts of 14 angstrom chlorite and 10 angstrom illite will produce peaks at these spacings of nearly equal size, and the 7 angstrom chlorite peak should be two to three times larger than the 10 angstrom peak of illite. However, the 10 angstrom illite peak was found to be larger than the 14 angstrom chlorite peak while the 7 angstrom chlorite peak is about one and one half times larger than the 10 angstrom peak. This would indicate an excess of illite over chlorite. Illite is therefore considered the dominant clay mineral of the Imperial formation with somewhat lesser amounts of chlorite.

The shales of the Imperial formation were found to contain a moderate amount of silt but very little sand. Quartz of coarse silt size may be seen in practically all shales of the formation. The quartz is all rounded to well rounded and may be frosted or relatively clear. Micaceous and chloritic material is extremely abundant in all the shales and is responsible for their fissility.

Carbonaceous material is extremely abundant in the lower shale unit but tends to decrease toward the upper shale unit. Spores, ostracods, and carbonaceous or bituminous material of indeterminable origin occur throughout the whole formation. Aggregates of minute crystalline pyrite are common and occasionally the shales have a slight reddish color perhaps indicative of hematite.

Source Rocks

The quartz grains of the Imperial sandstones commonly contain a predominance of irregular globular inclusions. Keller and Littlefield (1950) have proposed that inclusions of this type, combined with acicular inclusions, are indicative of an igneous rock origin. Although the quartz present within the sandstones of the formation may have been originally derived from igneous rocks it is probably multi-cycle and derived from reworked sediments. The subangular to subrounded nature of much of the quartz is not likely to have been achieved in one cycle, since fine quartz sand rounds very slowly. The small proportion of feldspar, which is also subangular to subrounded, suggests that igneous rocks were not a major source. Subangular to subrounded chert and microquartzite also attest to a source area of sediments.

The extreme abundance of mica and chlorite is difficult to explain by means other than a metamorphic source rock. Erosion of low-grade metamorphic rocks would explain the presence of these minerals without necessitating an influx of feldspars or other unstable minerals.

Rock fragments are not a large component of the Imperial sandstones. Much of the material is probably the result of reworking partially consolidated shale within the area of deposition. Those rock fragments which have an origin outside the area of deposition may be adequately explained as being derived from low-rank metamorphic or sedimentary rocks.

The sandstones of the Imperial formation are probably the result of erosion from a source area of sedimentary and slightly metamorphosed sedimentary rocks.

The heavy mineral suite identified from the Imperial formation is a stable suite common to rocks of late Paleozoic age (Pettijohn, 1957).

The general lack of angularity supports the other evidence for derivation from an area of sedimentary and low-rank metamorphic rocks. Heavy minerals present which are not derived from either of these two areas are authigenic or have formed as a result of organic decomposition.

Heavy minerals believed to be multi-cycle and derived from pre-existing sedimentary rocks are as follows:

Anatase and Leucoxene

Apatite

Rutile

Sphalerite

Spinel

Tourmaline

Zircon

Heavy minerals believed to be derived from low-rank metamorphic terrain are as follows:

Biotite and chlorite

Muscovite

Minerals having an authigenic or organic origin are as follows:

Collophane

Siderite

Hematite

Pyrite

Photomicrographs of the heavy minerals present are shown on plates 5 and 6.

SEDIMENTARY ENVIRONMENT AND PALEOECOLOGY

The Imperial formation, as explained in Chapter I, consists of three main units, a lower shale unit, a middle sandstone-shale unit and an upper shale unit. The upper and lower shale units contain a moderate amount of silt and relatively little sand. The middle sandstone-shale unit is composed of a rhythmic sequence of fine to very fine grained sandstones and shales.

Glaucinite occurs as an accessory mineral (less than 1 per cent) in many of the Imperial sandstones. Glaucinite is formed in marine environments and has been found in moderate (200-300 fathoms) to shallow (5-60 fathoms) depths (Murray and Renard, 1891; Galliher, 1935, 1939).

Cloud (1955) states that glauconite is formed in marine water near normal salinity and requires slightly reducing conditions. Formation appears to be favored by high organic content of the bottom sediments and slow sedimentation. Although glauconite may form from a broad range of substances, micaceous minerals or bottom muds of high iron content would provide appropriate source materials (Cloud, 1955). Examination of the Imperial formation revealed a complete absence of cross-bedding, ripple marks or any other features indicative of very shallow water deposition.

The shales of the Imperial formation have characteristics similar to the "Platform type" of depositional environment proposed by Krumbein (1947). Characteristics are uniform over large areas with transitional rather than abrupt lithologic changes. Fine textures

predominate and subrounded quartz is present in the silt sizes. Feldspar is uncommon and carbonaceous material is abundant. The shales are often slightly calcareous and are associated with quartzose sandstones. Color is a function of source materials, organic content and post-depositional conditions while textures are related to the energy of the transporting media. The inferred environment is a broad, relatively shallow open sea.

Marine depositional environment is shown by the presence of marine faunas. The Imperial formation carries relatively abundant brachiopoda, coelenterata and echinodermata which are dominantly marine forms.

Stromatoporoids occur within the Imperial formation and although their vertical distribution is restricted to certain horizons within the middle sandstone-shale unit they have wide lateral distribution throughout the formation. These organisms which are sessile benthonic have not been subjected to transportation and are therefore excellent ecological indicators. Stromatoporoids are indicative of a clear, warm, shallow water, marine environment (Galloway, 1957). The Imperial sea must therefore have been relatively shallow but may have been deeper than effective wave base. Although wave base is relative to the size of the body of water involved the depth of the Imperial sea, within the report area, would probably not exceed 600 feet. If stromatoporoids are analagous to Millepora and carried symbiotic algae then the depth would be less than 300 feet (Dr. C.R. Stelck, personal communication),

Corals are more common than stromatoporoids within the Imperial formation but none of the coelenterata are well developed. As the Imperial formation is dominantly shale the condition responsible for the restricted growth of these organisms was the muddy condition of the water. Although corals adapt themselves to muddy water much more readily than stromatoporoids, conditions were evidently too extreme for even these forms. This muddy condition of the water would affect the availability of sunlight, the availability of food and the carbonate content of the sea, all of which directly affect the abundance of organic life.

Maximum organic development occurs in the middle sandstone-shale unit. These sandstones represent a response to environmental variations within the area of deposition resulting in the accumulation of coarser clastics with a resultant temporary clearing of the sea. It is during these periods of relatively clear water that carbonates and associated biogenic limestones developed.

Large numbers of fossil spores were obtained from the Imperial formation and particularly from the lower shale unit of the Imperial formation (Plates 1 and 2). These spores were found to decrease in numbers from the lower part of the middle sandstone-shale unit up into the upper shale unit. The majority of the spores collected are greater than 200 microns and may be referred to as megaspores (Windslow, 1959). Because they are larger and heavier than small spores they probably were not as widely dispersed as microspores. The spores collected from the Imperial formation are

produced by terrestrial vascular plants and are probably derived from arborescent lycopods (Dr. J.D. Campbell, Research Council of Alberta, personal communication). Although megaspores are sometimes widely dispersed and can not be used as evidence of near shore conditions their distribution is more likely to be restricted to an area close to their site of production (Winslow, 1959). Spores were brought into the Imperial sea by rivers, streams and by wind action.

Scolecodonts were found in only one location within the upper shale unit of the formation. Some, but not all, of these forms show indications of abrasion due to transport (Plates 3 and 4). Modern polychaetes range from the shallow intertidal areas to the deeper zones of the sea, but are more commonly found on the tidal flats or near the low water mark. The forms collected from the Imperial formation are probably the result of transportation from shallower water conditions which existed to the west and northwest of the report area.

In summary the Imperial formation was deposited in a shallow marine environment. Sediments may have been deposited below effective wave base, but the water was shallow enough to allow the development of shallow, warm water organisms. The Imperial sea contained large amounts of clay and silt which may have restricted development of many benthonic shelled organisms. Sediments and terrestrial organic debris were supplied by a source area to the west or northwest of the report area. Maximum organic development occurs within the middle

sandstone-shale unit of the formation and is due to an increase in the clastic particle size which resulted in temporary clearing of the sea.

A summary of the macrofossils and microfossils collected from the Imperial formation are given below. Macrofossils were identified by Dr. C.R. Stelck, University of Alberta, 1960.

Phylum Brachiopoda

Atrypa sp.

Atrypa sp. aff. A. deflecta Warren

Camarotoechia sp. cf. C. contracta (Hall)

Chonetes sp.

?Cyrtospirifer sp.

Cyrtospirifer whitneyi (Hall)

?Gruendwaldtia sp.

Gypidula sp. cf. G. cornuta Fenton and Fenton

Hypothyridina sp. cf. H. emmonsii (Hall and Whitfield)

Productella sp.

?Spirifer sl. sp.

Stropheodonta sp.

Strophomena sp.

Theodossia sp.

Phylum Coelenterata

Class Anthozoa

Cladopora sp.Disphyllum sp. cf. D. colemanense WarrenTabulophyllum sp.Thamnopora sp.

Class Stomatoporoidea

Clathrocoilona sp.

Phylum Echinodermata

Class Crinoidea

Crinoid columnals

Phylum Mollusca

Class Gastropoda

Subclass Prosobranchia

Plagiothyra sp.

Subclass Opisthobranchia

Tentaculites sp.

Class Cephalopoda

Subclass Nautiloidea

Orthoceras sp.

Class Pelecypoda

Palaeneilo sp.?Pterinopecten sp.

Phylum Annelida

Class Polychaeta (Scolecodonts)

?Arabellites sp.

?Eunicites sp.

?Leodicites sp.

?Lumbriconereites sp.

?Nereidavus sp.

Phylum Arthropoda

*Subclass Ostracoda

?Kirkbyina sp.

Acratia sp.

Cytherella sp.

Plants

Algae

Megaspores

Triletes sp.

?Spencerisporites sp.

Microspores (Undifferentiated)

* Identified by Dr. R. Green, Research Council of Alberta

GEOLOGICAL HISTORY

The sediments of the Imperial formation have been derived from a source area of sedimentary, low rank metamorphic and possibly igneous rocks lying to the west or northwest of the report area. This is indicated by the subangular to subrounded multi-cycle nature of quartz, chert, feldspar and microquartzite within the sediments and the decreasing clastic particle size from northwest to southeast within the report area. The presence of a rounded, stable heavy mineral assemblage associated with abundant mica and chlorite constitute additional evidence for a source area of sedimentary and metamorphic rocks.

The region of the present day British-Barn Mountains has been considered as the source area for sediments of the Imperial formation by Martin (1959). Martin has suggested the British-Barn Mountains area may represent a part, or an isolated area at some distance from, a belt of high tectonic activity present to the north which was responsible for the deposition of miogeosynclinal and eugeosynclinal Late Devonian clastics from northern Ellesmere Island to northwestern Alaska. As the Middle Devonian of the Mackenzie River basin is dominantly non-clastic while other parts of the sedimentary belt, both Middle and Upper Devonian, are clastics, Martin suggests the sediments of this area were derived from an uplifted element not directly connected with the main belt of orogeny.

The orogeny responsible for uplift in the British-Barn Mountains area took place in late Middle Devonian or Upper Devonian time (Martin, 1959).

The depositional environment as explained under Paleoecology was shallow marine. Sediments were deposited in the Imperial sea in water believed to be deeper than effective wave base but shallow enough for shallow, warm water organisms such as stromatoporoids to develop. Abundant terrestrial organic material such as megaspores indicate the presence of land at some intermediate distance to the west or northwest of the report area.

Regression of the Late Devonian sea may have occurred earlier in the report area than in the North Nahanni-Root River area of the Northwest Territories as beds are present within this latter area which are stratigraphically higher than those of the report area. As the Imperial formation within the report area is overlain unconformably by Cretaceous strata Late Palaeozoic sediments were either never deposited or were removed prior to the transgression of the Cretaceous sea.

Cretaceous strata within the Mackenzie River basin may attain thicknesses of 5,100 to 5,200 feet (Hume, 1954). Stelck and Hart (in Hume, 1954) have reported 600 feet and 1600 feet of Tertiary (Eocene) strata respectively from the Mackenzie River basin. Total depth of overburden upon the Imperial formation may locally exceed 6,700 feet.

The Mackenzie Mountains along with the Franklin and Richardson Mountains are part of the eastern Cordillera region and are basically Laramide in origin (Eardley, 1951). Deformation within the area of this report has generally taken the form of broad open folds.

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APPENDIX A

Section Descriptions

Imperial River Section

Cretaceous Sans Sault Formation?

<u>Distance Below Highest Exposure</u>	<u>Thickness</u>	
0'-9'	9'	<u>Sandstone</u> - light olive gray to greenish gray, very fine-grained, laminated thin-bedded*, non-calcareous, glauconitic, slightly micaceous, fairly porous.
9'-39'	30'	<u>Shale</u> - brownish black, non-calcareous, friable.
39'-56'	17'	<u>Sandstone</u> - light olive gray, very fine-grained, very thin-bedded to thin-bedded, strongly cross-bedded, well indurated, non-calcareous, glauconitic.
56'-130'	74'	<u>Shale</u> - brownish black, non-calcareous, friable, ferruginous, pyritic clay ironstone concretions up to 6' long and 1 1/2' in diameter are present. Contains abundant arenaceous and minor calcareous foraminifera: <u>Ammobaculites</u> sp. <u>Bathysiphon</u> sp. <u>Gyroidina</u> sp. <u>Haplophragmoides</u> sp. <u>Proteonina</u> sp. <u>Saccamina</u> sp. <u>Saracenaria</u> sp. <u>Trochammina</u> sp. <u>?Verneuilina</u> sp.

* Bedding terminology after McKee and Weir (1953).

Very-thick bedded - greater than 4 feet.

Thick-bedded - 4 feet to 2 feet.

Thin-bedded - 2 feet to 2 inches.

Very-thin bedded - 2 inches to 1/2 inch.

Laminated - 1/2 inch to 1/10 inch.

Thinly laminated - less than 1/10 inch.

130'-145'	15'	<u>Sandstone</u> - light olive gray, fine-grained, thin-bedded to thick-bedded, non-calcareous, very glauconitic, quartzitic, conglomeratic, contains sub-rounded to rounded quartz and chert pebbles.
145'-145.5'	.5'	<u>Conglomerate</u> , pebble, very light gray to dark gray, sub-rounded to rounded, occasionally well rounded, mainly quartz and chert, maximum diameter 2", average diameter 1". Matrix, sand, very fine-grained, micaceous, ferruginous, glauconitic, slightly pyritic, fairly porous. Lower contact, with Late Devonian shale, is sharp while upper contact is gradational into Cretaceous sandstone.

Late Devonian Imperial Formation

<u>Distance Below Top</u>	<u>Thickness</u>	
0'-6'	6'	<u>Shale</u> - moderate yellowish brown to medium light gray, fairly well indurated, non-calcareous. <u>Acratia</u> sp.
6'-16'	10'	<u>Shale</u> - greenish gray to medium dark gray, contains occasional bands of siltstone up to 1/2" thick. <u>Acratia</u> sp.
16'-338'	322'	<u>Shale</u> - medium dark gray, non-calcareous, friable.
338'-438'	100'	<u>Covered Interval</u> - probably shale, as above.
438'-490'	52'	<u>Shale</u> - medium gray, non-calcareous, friable.
490'-528'	38'	<u>Sandstone</u> - greenish gray, very fine-grained, slightly laminated, very thin-bedded to thin-bedded, calcareous, very slightly glauconitic and micaceous, contains: <u>Camarotoechia</u> sp. cf. <u>C. contracta</u> (Hall)

528'-585'	57'	<u>Shale</u> - medium gray, non-calcareous, friable, occasional very fine-grained sandstone to siltstone beds up to 2" thick.
585'-598'	13'	<u>Sandstone</u> - greenish gray, very fine-grained, laminated, thin-bedded, very slightly calcareous.
598'-628'	30'	<u>Shale</u> - medium gray to dark greenish gray, non-calcareous, fairly well indurated, slightly ferruginous.
628'-648'	20'	<u>Shale</u> - as in unit 598'-628' but contains occasional very fine grained sandstone beds 1" to 2" thick.
648'-682'	34'	<u>Shale</u> - as in unit 598'-628'.
682'-683'	1'	<u>Sandstone</u> - as in unit 585'-598' but is calcareous and contains: <u>Cyrtospirifer whitneyi</u> (Hall)
683'-693'	10'	<u>Sandstone</u> - as in unit 585'-598'.
693'-755'	62'	<u>Shale</u> - as in unit 598'-628'.
755'-760'	5'	<u>Sandstone</u> - as in unit 585'-598'.
760'-761'	1'	<u>Sandstone</u> - as in unit 585'-598' but calcareous and contains: <u>Cyrtospirifer whitneyi</u> (Hall) var. <u>Productella</u> sp.
761'-768'	7'	<u>Sandstone</u> - greenish gray, very fine-grained, laminated thin-bedded, very slightly calcareous.
768'-793.5'	25.5'	<u>Shale</u> - medium gray to dark greenish gray, non-calcareous, fairly well indurated, abundant carbonaceous fragments.
793.5'-794'	0.5'	<u>Sandstone and Shale</u> Shale - similar to unit 798'-793.5'. Sandstone - similar to unit 761'-768', but both are calcareous.

794'-795.5'	1.5'	<u>Shale</u> - as in unit 768'-793.5'.
795.5'-796'	0.5'	<u>Sandstone and Shale</u> - as in unit 793.5'-794', extremely calcareous and contains: <u>Orthoceras</u> sp. <u>Plagiothyra</u> sp. <u>Theodossia</u> sp. <u>Cyrtospirifer whitneyi</u> (Hall)
796'-797.5'	1.5'	<u>Shale</u> - as in unit 768'-793.5'.
797.5'-798	0.5'	<u>Sandstone and Shale</u> - as in unit 793.5'-794', extremely cal- careous.
798'-806'	8'	<u>Shale</u> - as in unit 768'-793.5'.
806'-814.5'	8.5'	<u>Sandstone</u> - greenish gray, very fine- grained, laminated thin-bedded, very slightly calcareous.
814.5'-815'	0.5'	<u>Sandstone</u> - as in unit 806'-814.5' but contains abundant rounded to sub-angular shale pebbles and organic fragments.
815'-818'	3'	<u>Sandstone</u> - as in unit 806'-814.5'.
818'-828'	10'	<u>Shale</u> - medium gray, non-calcareous, fairly well indurated, micaceous with abundant carbonaceous frag- ments, slightly pyritic.
828'-837'	9'	<u>Sandstone</u> - greenish gray, very fine- grained, laminated thin-bedded, very slightly calcareous.
837'-838'	1'	<u>Sandstone</u> - greenish gray to dark greenish gray, very fine-grained, irregularly bedded, cross-lam- inated, rounded to sub-angular shale pebbles present, organic fragments abundant, slightly pyritic.
838'-858'	20'	<u>Sandstone</u> - greenish gray, very fine grained to <u>siltstone</u> , laminated very thin-bedded to thin-bedded, cross-laminated with abundant shale laminae, non-calcareous.

858'-893'	35'	<u>Sandstone and Shale</u> Sandstone - greenish gray, very fine-grained, laminated to very thin-bedded, non-calcareous. Shale - medium gray, non-calcareous, slightly micaceous, fairly well indurated.
893'-912'	19'	<u>Sandstone</u> - greenish gray, very fine-grained to siltstone, laminated very thin-bedded, non-calcareous, micaceous, slightly glauconitic.
912'-913'	1'	<u>Sandstone</u> - dark yellowish brown, very fine-grained, very thin-bedded, contains abundant rounded to sub-rounded shale pebbles and angular fragments of organic material, extremely ferruginous, very calcareous, contains: Gastropods Crinoid stems.
913'-918'	5'	<u>Sandstone</u> - greenish gray, very fine-grained to <u>siltstone</u> , laminated very thin-bedded, non-calcareous, micaceous, slightly glauconitic.
918'-928'	10'	<u>Sandstone and Shale</u> Sandstone - greenish gray, very fine-grained, laminated to very thin-bedded, non-calcareous. Shale - medium gray, non-calcareous, slightly micaceous, fairly well indurated, predominant part of the unit.
928'-938'	10'	<u>Sandstone</u> - greenish gray, very fine-grained, laminated very thin- to thick-bedded, cross-laminated, well indurated, slightly glauconitic, micaceous, irregular bitumen staining, slightly calcareous, locally shale lenses and fragments up to 1' long are abundant, limestone lenses 2" thick and 6" long are present containing: <u>Theodossia</u> sp.

938'-953'	15'	<u>Sandstone and Shale</u> Sandstone - greenish gray, very fine-grained to <u>siltstone</u> , laminated to very thin-bedded, micaceous, non-calcareous. Shale - medium dark gray, non-calcareous.
953'-1008'	55'	<u>Shale</u> - medium dark gray, non-calcareous, micaceous.
1008'-1008.5'	0.5'	<u>Limestone</u> - light olive gray to pale yellowish brown, very fine-grained, arenaceous, contains: <u>Camarotoechia</u> sp. cf. <u>C. contracta</u> (Hall) <u>Disphyllum</u> sp. cf. <u>D. colemanense</u> Warren
1008.5'-1023'	14.5'	<u>Sandstone</u> - greenish gray, very fine-grained to <u>siltstone</u> , laminated to very thin-bedded, calcareous, micaceous.
1023'-1055'	32'	<u>Shale</u> - medium dark gray, non-calcareous, micaceous, fairly well indurated.
1055'-1056'	1'	<u>Limestone</u> - light olive gray to pale yellowish brown, very fine-grained, arenaceous, contains small shale lenses.
1056'-1082.5'	26.5'	<u>Sandstone</u> - greenish gray, very fine-grained to <u>siltstone</u> , thinly laminated very thin- to thick-bedded.
1082.5'-1083'	0.5'	<u>Limestone</u> - light olive gray to pale yellowish brown, very fine-grained, very arenaceous, organic fragments extremely abundant, bitumen and carbonaceous material common on bedding planes and fractures, contains: <u>Theodossia</u> sp. <u>Cyrtospirifer whitneyi</u> (Hall) Crinoid columnals.

1083'-1087'	4'	<u>Sandstone</u> - greenish gray, very fine-grained to <u>siltstone</u> , thinly laminated very thin- to thick-bedded, non-calcareous.
1087'-1088'	1'	<u>Limestone</u> - light olive gray to pale yellowish brown, very fine-grained, very arenaceous, slightly micaceous, slightly glauconitic, rhombohedral calcite infillings, abundant bitumen staining, contains: <u>Disphyllum</u> sp. cf. <u>D. colemanense</u> Warren <u>Tabulophyllum</u> sp. <u>Thamnopora</u> sp. <u>Clathrocoelona</u> sp. Algae
1088'-1108'	20'	<u>Shale</u> - medium gray, non-calcareous, friable, slightly ferruginous.
1108'-1128'	20'	<u>Sandstone</u> - greenish gray, very fine-grained to siltstone, thinly laminated, very thin-bedded to thin-bedded, slightly cross-laminated, micaceous, abundant carbonaceous particles, very slightly calcareous, contains: <u>?Cyrtospirifer</u> sp.
1128'-1168'	40'	<u>Shale</u> - medium gray, non-calcareous, friable, slightly ferruginous.
1168'-1238'	70'	<u>Sandstone</u> - greenish gray to medium gray, very fine-grained to <u>siltstone</u> , thinly laminated thin to thick-bedded, non-calcareous, micaceous, abundant carbonaceous particles, very slightly glauconitic, fucoid markings on bedding planes.
1238'-1433'	195'	<u>Shale</u> - medium dark gray, non-calcareous, friable, slightly micaceous.

1433'-1483'	50'	<u>Sandstone</u> - greenish gray to medium gray, very fine-grained to <u>siltstone</u> , thinly laminated thin- to thick-bedded, non-calcareous, micaceous, abundant carbonaceous particles, slightly glauconitic, furoid markings on bedding planes.
1483'-1573'	90'	<u>Shale</u> - medium dark gray, non-calcareous, friable, slightly micaceous.
1573'-1718'	145'	<u>Sandstone and Shale</u> Sandstone - greenish gray, very fine-grained to <u>siltstone</u> , thinly laminated very thin- to thick-bedded, slightly cross-laminated, well indurated, abundant carbonaceous particles, slightly calcareous, slightly glauconitic, micaceous, occasional thin shale lenses, composes the bulk of the unit. Shale - medium dark gray, non-calcareous, friable, slightly micaceous, occurs in beds up to 6" thick.

The lower shales of the Imperial Formation are not exposed at this point.

Canol Road Section

Late Devonian Imperial Formation

Upper portion of the Imperial formation
not exposed.

<u>Distance Below Highest Exposure</u>	<u>Thickness</u>	
0'-110'	110'	<u>Sandstone</u> - greenish gray to light olive gray, very fine-grained, laminated very thin- to thin-bedded, micaceous, abundant carbonaceous particles, slightly calcareous to very calcareous. Occasional <u>shale</u> bed up to 4" thick.
110'-190'	80'	<u>Covered Interval</u> - believed to be shale as in unit 190'-580'.
190'-580'	390'	<u>Shale</u> - greenish gray, non-calcareous, slightly arenaceous, micaceous, abundant carbonaceous particles, very slightly ferruginous, very friable, unit it strongly slumped.
580'-760'	180'	<u>Covered Interval</u> - believed to be shale as in unit 190'-580'.

Late Devonian Fort Creek Formation

<u>Distance Below Top</u>	<u>Thickness</u>	
0'-75'	75'	<u>Shale</u> - dark gray to grayish black, bituminous, non-calcareous, pyritic, clay ironstone beds and nodules occur regularly throughout the unit. Contains: <u>Entomis</u> sp. cf. <u>E. variostriata</u> Clarke. <u>Entomis</u> sp. cf. <u>E. serratostriata</u> (Sandberger)

75'-480'	355'	<u>Shale</u> - dark gray to grayish black, bituminous, non-calcareous, ferruginous, contains occasional clay ironstone beds up to 1' thick.
430'-607'	177'	<u>Shale</u> - medium dark gray to dark gray, bituminous, non-calcareous, very well indurated, occasional medium dark gray pyritic limestone nodules up to 3 1/2" in diameter are present.

Carcajou River Section

Late Devonian Imperial Formation

<u>Distance Below Highest Exposure</u>	<u>Thickness</u>	
0'-35.5'	35.5'	<u>Shale</u> - olive gray, non-calcareous, well indurated. *? <u>Kirbyina</u> sp. <u>Acratia</u> sp. <u>Cythercella</u> sp.
35.5'-36'	0.5'	<u>Shale</u> - moderate yellowish brown, extremely calcareous, contains: <u>Cyrtospirifer whitneyi</u> (Hall) var. <u>Camarotoechia</u> sp.
36'-44.5'	8.5'	<u>Shale</u> - olive gray, non-calcareous, well indurated.
44.5'-45'	0.5'	<u>Shale</u> - moderate yellowish brown, extremely calcareous, extremely fossiliferous, contains: <u>Cyrtospirifer whitneyi</u> (Hall) var. <u>Camarotoechia</u> sp.
45'-50.5'	5.5'	<u>Shale</u> - olive gray, non-calcareous, fairly well indurated.
50.5'-51'	0.5'	<u>Shale</u> - olive gray to dark yellowish brown, contains numerous rounded to subrounded greenish gray shale pebbles oriented parallel to the bedding, calcareous, ferruginous, extremely fossiliferous, contains: <u>Cyrtospirifer whitneyi</u> (Hall) <u>Productella</u> sp.
51'-60'	9'	<u>Shale</u> - olive gray, non-calcareous, fairly well indurated.
60'-80'	20'	<u>Sandstone and Shale</u> Sandstone - light olive gray to brown- ish gray, very fine-grained to <u>siltstone</u> , slightly laminated, very thin- to thin-bedded, slightly micaceous and glauconitic, marked color variation within laminae. Shale - olive gray, non-calcareous, friable.

* All three genera are found from 0'-60'.

80'-88'	8'	<u>Sandstone</u> - light olive gray to brownish gray, very fine-grained to <u>siltstone</u> , slightly laminated, very thin- to thin-bedded, slightly calcareous, slightly micaceous, slightly glauconitic. Contains: <u>?Pterinopecten</u> sp.
88'-100'	12'	<u>Sandstone and Shale</u> - as in unit 60'-80' but contains: <u>Paleoneilo</u> sp. <u>Camarotoechia</u> sp. <u>Productella</u> sp. <u>?Pterinopecten</u> sp.
100'-106'	6'	<u>Sandstone</u> - as in unit 80'-88'.
106'-111'	5'	<u>Sandstone and Shale</u> - as in unit 60'-80'.
111'-120'	9'	<u>Sandstone</u> - as in unit 80'-88'.
120'-127'	7'	<u>Sandstone and Shale</u> - as in unit 60'-80'.
127'-136'	9'	<u>Sandstone</u> - as in unit 80'-88'.
136'-161'	25'	<u>Sandstone and Shale</u> - as in unit 60'-80'.
161'-170'	9'	<u>Sandstone</u> - as in unit 80'-88' but is laminated to very thin-bedded, calcareous and extremely fossiliferous, contains: <u>Theodossia</u> sp. <u>Chonetes</u> sp. <u>Tentaculites</u> sp.
170'-185'	15'	<u>Sandstone and Shale</u> <u>Sandstone</u> - dark greenish gray, very fine-grained to <u>siltstone</u> , very thin- to thin-bedded, micaceous, abundant carbonaceous particles. <u>Shale</u> - olive gray to dark greenish gray, non-calcareous, friable.
185'-210'	25'	<u>Sandstone</u> - light olive gray to brownish gray, very fine-grained to <u>siltstone</u> , slightly laminated, very thin- to thin-bedded, slightly calcareous, slightly micaceous and glauconitic.

210'-270'	60'	<u>Sandstone and Shale</u> Sandstone - light olive gray to greenish gray, very fine-grained to <u>siltstone</u> , very thin- to thin-bedded, non-calcareous, slightly micaceous. Shale - olive gray, non-calcareous, micaceous, abundant carbonaceous particles.
270'-280'	10'	<u>Sandstone</u> - as in unit 210'-270'.
280'-300'	20'	<u>Sandstone and Shale</u> - as in unit 210'-270'.
300'-311'	11'	<u>Sandstone</u> - brownish gray, very fine-grained to siltstone, very thin- to thin-bedded, extremely ferruginous, calcareous, fossiliferous toward the base of the unit, contains: <u>Chonetes</u> sp. <u>Theodossia</u> sp.
311'-321'	10'	<u>Sandstone and Shale</u> - as in unit 210'-270'.
321'-346'	25'	<u>Sandstone</u> - light olive gray to greenish gray, very fine-grained to <u>siltstone</u> , very thin- to thin-bedded, non-calcareous, slightly micaceous.
346'-352'	6'	<u>Sandstone</u> - as in unit 321'-346'.
352'-356'	4'	<u>Sandstone</u> - brownish gray, very fine-grained to <u>siltstone</u> , very thin- to thin-bedded, extremely calcareous, micaceous, slightly glauconitic, ferruginous.
356'-369'	13'	<u>Shale</u> - olive gray, non-calcareous, micaceous, abundant carbonaceous particles.
369'-375'	6'	<u>Sandstone</u> - as in unit 352'-356' but non-calcareous.
375'-400'	25'	<u>Shale</u> - as in unit 356'-369'.

400'-410'	10'	<u>Sandstone</u> - as in unit 352'-356' but non-calcareous.
410'-415'	5'	<u>Shale</u> - as in unit 356'-369'.
415'-420'	5'	<u>Sandstone</u> - as in unit 352'-356' but non-calcareous.
420'-436'	16'	<u>Shale</u> - as in unit 356'-369'.
436'-443'	7'	<u>Sandstone</u> - greenish gray, very fine-grained to <u>siltstone</u> , very thin- to thin-bedded, non-calcareous, abundant carbonaceous material along bedding planes.
443'-507'	64'	<u>Sandstone and Shale</u> Sandstone - light olive gray to greenish gray, very fine-grained to <u>siltstone</u> , very thin- to thin-bedded, non-calcareous, slightly micaceous. Shale - olive gray, non-calcareous, micaceous, abundant carbonaceous particles.
507'-508'	1'	<u>Limestone</u> - pale yellowish brown, irregularly bedded, abundant organic material, irregular bitumen staining.
508'-517'	9'	<u>Sandstone</u> - light olive gray to greenish gray, very fine-grained to <u>siltstone</u> , very thin- to thin-bedded, non-calcareous.
517'-518'	1'	<u>Limestone</u> - pale yellowish brown, very fine-grained, irregularly bedded, abundant organic material, contains: Theodossia sp.
518'-539'	21'	<u>Sandstone</u> - light olive gray to greenish gray, very fine-grained to <u>siltstone</u> , laminated very thin- to thin-bedded, non-calcareous.
539'-540'	1'	<u>Limestone</u> - olive gray to medium gray, very fine-grained, irregularly bedded, irregular bitumen staining, abundant organic material.

540'-545'	5'	<u>Sandstone</u> - light olive gray to greenish gray, very fine grained to <u>siltstone</u> , cross-laminated, very thin- to thin-bedded, non-calcareous, abundant carbonaceous particles.
545'-558'	13'	<u>Sandstone and Shale</u> Sandstone - olive gray, very fine-grained to <u>siltstone</u> , laminated to very thin-bedded, non-calcareous. Shale - olive gray, non-calcareous, friable.
558'-559'	1'	<u>Limestone</u> - olive gray to medium gray, very fine-grained, irregularly bedded, irregular bitumen staining, abundant organic material, contains: <u>Cladopora</u> sp. <u>Clathrocoilon</u> sp.
559'-574'	15'	<u>Sandstone and Shale</u> Sandstone - olive gray, very fine-grained to siltstone, laminated to very thin-bedded, non-calcareous, micaceous. Shale - olive gray, non-calcareous, friable.
574'-575'	1'	<u>Sandstone</u> - dark greenish gray, very fine-grained to siltstone, very thin- to thin-bedded, calcareous, bitumen staining, abundant organic material, contains: <u>Disphyllum colemanense</u> Warren
575'-582'	7'	<u>Sandstone</u> - dark greenish gray, very fine-grained to <u>siltstone</u> , laminated to very thin-bedded, slightly calcareous.
582'-583'	1'	<u>Sandstone</u> - dark greenish gray, very fine-grained to <u>siltstone</u> , very thin- to thin-bedded, calcareous, irregular bitumen staining, angular to subangular organic fragments common, present are:

Gruendwaldtia sp.
Productella sp.
Tentaculites sp.
Hypothyridina sp. cf. H.
emmonsi (Hall and Whitfield)

583'-604'	21'	<u>Sandstone</u> - dark greenish gray, very fine-grained to <u>siltstone</u> , laminated to thin-bedded.
604'-623.5'	19.5'	<u>Sandstone</u> - light olive gray, very fine-grained to <u>siltstone</u> , very thin- to thin-bedded, calcareous, slightly ferruginous.
623.5'-624'	0.5'	<u>Sandstone</u> - medium light gray to greenish gray, very fine- to fine-grained, irregularly bedded, contains abundant glauconite and carbonate cement, ferruginous, bitumen staining common, contains: <u>Gypidula</u> sp. cf. <u>G. cornuta</u> Fenton and Fenton <u>Clathrocoilona</u> sp. <u>Camarotoechia</u> sp.
624'-643'	19'	<u>Sandstone</u> - light olive gray, very fine-grained to siltstone, laminated very thin- to thin-bedded, calcareous, irregular bitumen staining present, slightly ferruginous.
643'-673'	30'	<u>Shale</u> - light olive gray, calcareous, silty, ferruginous, contains occasional sandstone beds up to 2" thick.
673'-680'	7'	<u>Sandstone</u> - greenish gray, very fine grained to <u>siltstone</u> , cross-laminated very thin- to thin-bedded, calcareous, micaceous, occasional carbonaceous particles, irregular blebs and lenses of shale.
680'-690'	10'	<u>Shale</u> - olive gray, non-calcareous, very slightly micaceous.

690'-695'	5'	<u>Sandstone</u> - light olive gray, very fine-grained to <u>siltstone</u> , very thin-bedded, calcareous, slightly ferruginous.
695'-745'	50'	<u>Shale</u> - olive gray, non-calcareous, very slightly micaceous.
745'-757'	12'	<u>Sandstone</u> - light olive gray, very fine-grained to <u>siltstone</u> , very thin- to thin-bedded, calcareous, irregular bitumen staining common, slightly ferruginous.
757'-767'	10'	<u>Sandstone</u> - light olive gray, very fine-grained to <u>siltstone</u> , laminated to very thin-bedded, non-calcareous, contains numerous shale laminations.
767'-792'	25'	<u>Shale</u> - olive gray non-calcareous, very slightly micaceous, occasional carbonaceous particles, very slightly pyritic.
792'-897'	105'	<u>Sandstone</u> - greenish gray, very fine-grained to <u>siltstone</u> , laminated very thin- to thin-bedded, non-calcareous, slightly micaceous and glauconitic, bitumen lenses up to 1/2" in length are present, calcareous and fossiliferous, contains: <u>Atrypa</u> sp. cf. <u>A. deflecta</u> Warren
897'-952'	55'	<u>Shale</u> - medium dark gray, non-calcareous, fairly well indurated.
952'-972'	20'	<u>Sandstone</u> - greenish gray, very fine-grained to <u>siltstone</u> , very thin- to thin-bedded, very slightly calcareous, slightly micaceous.
972'-1017'	45'	<u>Shale</u> - medium dark gray, non-calcareous, slightly silty, contains occasional limestone concretions.

1017'-1062'	45'	<u>Sandstone and Shale</u> Sandstone - light olive gray, very fine-grained to <u>siltstone</u> , laminated to very thin-bedded, very slightly calcareous, predominant part of the unit. Shale - olive gray, non-calcareous, silty.
1062'-1077.5'	15.5'	<u>Shale</u> - olive gray silty, non-calcareous, slightly micaceous, abundant carbonaceous particles, contains occasional siltstone bands.
1077.5'-1078'	.5'	<u>Limestone</u> - medium dark gray, very fine-grained, thin-bedded.
1078'-1334'	256'	<u>Shale</u> - olive gray, non-calcareous, slightly micaceous, abundant carbonaceous particles, friable. Contains a 3" medium dark gray very fine-grained limestone band at the base.
1334'-1427'	93'	<u>Shale</u> - olive gray, non-calcareous, slightly micaceous, abundant carbonaceous particles, friable, contains occasional sandstone beds up to 1/2" thick.

Basal beds of the Imperial formation are not exposed at this point.

Redstone Tributary Section

Late Devonian Imperial Formation

<u>Depth Below Highest Exposure</u>	<u>Thickness</u>	
0'-180'	180'	<u>Shale</u> - medium gray, non-calcareous, micaceous, abundant carbonaceous particles, fairly well indurated, slightly ferruginous.
180'-225'	45'	<u>Sandstone and Shale</u> Sandstone - medium gray to medium dark gray, very fine-grained to <u>siltstone</u> , laminated very thin- to thin-bedded, non-calcareous, slightly micaceous, argillaceous. Shale - medium dark gray, micaceous, non-calcareous, occasional carbonaceous particles.
225'-500'	275'	<u>Covered Interval</u>
500'-614'	114'	<u>Sandstone and Shale</u> Sandstone - medium gray to medium dark gray, very fine-grained to <u>siltstone</u> , laminated very thin- to thin-bedded, non-calcareous, slightly micaceous, argillaceous. Shale - medium gray to medium dark gray, micaceous, non-calcareous, occasional carbonaceous particles.
614'-623'	9'	<u>Sandstone</u> - light olive gray to medium gray, very fine-grained to <u>siltstone</u> , laminated thin to thick-bedded, micaceous, slightly calcareous, argillaceous.
623'-636'	13'	<u>Sandstone and Shale</u> Sandstone - medium dark gray, very fine-grained to <u>siltstone</u> , very thin- to thin-bedded, non-calcareous. Shale - medium dark gray, non-calcareous, slightly micaceous, fairly well indurated.

636'-660'	24'	<u>Sandstone</u> - light olive gray to medium gray, very fine-grained to <u>siltstone</u> , laminated thin- to thick-bedded, micaceous, slightly calcareous, slightly ferruginous.
660'-880'	220'	<u>Sandstone and Shale</u> Sandstone - medium gray to medium dark gray, very fine-grained to <u>siltstone</u> , very thin- to thin-bedded, non-calcareous, slightly micaceous, well indurated, argillaceous, contains occasional rounded dark gray shale pebbles up to 1" in length. At intervals the sandstone contains dark gray, fine-grained fossiliferous irregularly bedded limestone up to 1 foot thick. These occur at: 720' - <u>Chonetes</u> sp. 828' - <u>Stropheodonta</u> sp. Coral 833' - ? <u>Spiriferid</u> sp. Shale - medium dark gray to dark gray, silty, non-calcareous, slightly micaceous, well indurated.
880'-883'	3'	<u>Sandstone</u> - medium dark gray, very fine grained to <u>siltstone</u> , laminated very thin- to thin-bedded, pyritic, ferruginous, slightly micaceous, calcareous, contains occasional dark gray shale lenses up to 1/2" in length, abundant angular organic fragments.
883'-1016'	133'	<u>Sandstone and Shale</u> Sandstone - medium gray to medium dark gray, very fine-grained to <u>siltstone</u> , laminated to thin-bedded, micaceous, non-calcareous, argillaceous. At intervals the sandstone contains <u>limestone</u> , medium dark gray to dark gray, fine-grained, silty, fossiliferous, irregularly bedded up to 1 foot thick. These occur at:

- 975' - Stropheomena sp.
 1013' - Disphyllum sp. cf. D. colemanense Warren

Shale - medium dark gray, non-calcareous, micaceous.

1016'-1108'

92'

Sandstone and Shale

Sandstone - medium dark gray, very fine-grained to siltstone, laminated to very thin-bedded, argillaceous, non-calcareous, slightly micaceous.

Shale - medium dark gray, non-calcareous, silty, well indurated.

1108'-1260'

152'

Sandstone and Shale

Sandstone - medium dark gray, very fine-grained to siltstone, laminated to very thin-bedded, slightly micaceous, argillaceous, very slightly calcareous.

Shale - medium gray to medium dark gray, non-calcareous, silty, well indurated.

1260'-1358'

98'

Sandstone and Shale

Sandstone - medium dark gray, very fine-grained to siltstone, laminated very thin- to thin-bedded, non-calcareous, slightly micaceous, argillaceous.

Shale - medium dark gray, thinly laminated to laminated, slightly calcareous, micaceous, abundant carbonaceous particles.

1358'-1416'

58'

Shale - medium dark gray, silty, thinly laminated to laminated, very well indurated, non-calcareous, slightly micaceous.

1416'-1761'

345'

Shale - medium dark gray, non-calcareous, soft and friable, contains occasional very thin beds of medium dark gray sandstone.

Late Devonian Fort Creek Formation?Siltstone and Shale

Siltstone - medium dark gray, cross-laminated, very thin- to thin-bedded, well indurated, argillaceous.

Shale - medium dark gray, non-calcareous, slightly ferruginous, slightly silty. Predominant part of the unit.

APPENDIX B

Description of Selected Thin Sections

Thin Section number - 4058

Location - Imperial River Section 1668'-1718'

Formation - Imperial Formation

Description:

Color - fresh surface - greenish gray.

Texture - clastic, very fine sand, subangular to angular, fairly well sorted, well indurated, poorly cemented, no porosity.

Essential Components:

- 50% Quartz - grains angular to subangular, rarely rounded, average size 0.1 mm., few contacts, grains separated by matrix and cement, overgrowths rare, inclusions common, irregular globular or irregular dusty, 50% strained.
- 7% Chert and microquartzite
- 4% Feldspar - twinned plagioclase and potash variety.
- 9% Rock Fragments - micaceous and chloritic rocks.

Varietal Minerals:

- 5% Biotite and chlorite
- 2% Muscovite
- 1% Carbonaceous material

1% Accessory Minerals:

Zircon

Anatase and leucoxene

Glaucconite

- 10% Matrix: Micaceous and chloritic phyllosilicates.

Cement:

- 5% Calcite
- 6% Siderite (spherulitic)

Classification: Lithic sandstone

Thin Section number - 4061

Location - Imperial River Section 1055'-1088'

Formation - Imperial Formation

Description:

Color - fresh surface - greenish gray.

Texture - bioclastic, very coarse to very fine sand, poorly sorted, well indurated, well cemented, no porosity.

Essential Components:

- 20% Carbonate shell material - Brachiopods, ostracods, tentaculinids, echinoderm plates, gastropods, bryozoa.
- 5% Sideritized shell material - same forms as above, siderite in the form of spherules.
- 15% Quartz - grains subangular to rounded, generally sub-rounded, average size 0.1 mm., contacts rare, overgrowths rare, inclusions common, irregular globular and irregular dusty, regular inclusions rare, occasional well developed "bubble trails", 50% strained.
- 5% Chert and microquartzite
- 3% Feldspar - plagioclase and potash variety.
- 1% Rock Fragments

1% Accessory Minerals:

Mica (muscovite, biotite)

Chlorite

Anatase and leucoxene

Zircon

Cement:

47% Calcite

4% Siderite

Classification: Quartzitic biocalcarenite

Thin Section number - 4062

Location - Imperial River Section 928'-938'

Formation - Imperial Formation

Description:

Color - fresh surface - greenish gray

Texture - clastic, very fine to fine sand, subangular to subrounded, fairly well sorted, well indurated, poorly cemented, no porosity.

Essential Components:

45% Quartz - grains subangular to subrounded, generally subangular, average size 0.1 mm., 0-3 contacts per grain, grains generally separated by matrix and cement, overgrowths rare, inclusions common but not abundant, generally irregular dusty or globular, 50% strained.

11% Chert and microquartzite

4% Feldspar - twinned plagioclase and potash variety.

7% Rock Fragments - argillaceous, subrounded to subangular.

Varietal Minerals:

5% Mica (biotite, muscovite), Chlorite

2% Carbonate shell material - echinoid plates, brachiopod shells

1% Carbonaceous material

1% Accessory Minerals:

Collophane - fish bone

14% Matrix:

Micaceous and chloritic phyllosilicates

Cement:

10% Calcite

1% Siderite

Classification: Lithic sandstoneThin Section number - 4063Location - Imperial River Section 912'-913'Formation - Imperial FormationDescription:

Color - fresh surface - dark yellowish brown

Texture - clastic, fine to coarse sand, generally fine sand, oolitic in part, fairly well sorted, well indurated, well cemented, no porosity.

Essential Components:

28% Quartz - grains subangular to subrounded, generally subangular, average size 0.1-0.15 mm., few contacts, grains separated by cement, hematite abundant, inclusion common but not abundant, usually irregular dusty to globular, 50% strained.

5% Chert and microquartzite4% Feldspar18% Oolitic and detrital hematite1% Rock fragments - argillaceous, subrounded to subangular.

Organic material:

- 7% Carbonate shell material - echinoid plates, crinoid columnals, ostracods, brachiopods.
- 13% Collophane and carbonaceous material - fish bone, plant fragments, spores.

Cement:

- 15% Calcite
- 4% Hematite
- 5% Siderite

Classification: Phosphatic hematitic bioclastic arenite

Thin Section number - 4066

Location - Imperial River Section 130'-145'

Formation - Cretaceous (Sans Sault Formation?)

Description:

Color - fresh surface - light olive gray.

Texture - clastic, medium to fine sand, subangular to subrounded, generally subrounded, fairly well sorted, poorly indurated, no cement, no matrix, fair porosity.

Essential Components:

- 89% Quartz - grains subangular to subrounded, generally subrounded, average size 0.15 mm., several contacts per grain, overgrowths common, inclusions common, usually irregular globular or dusty, rarely regular, occasional acicular inclusions and "bubble trains" present, 50% strained.
- 2% Chert and microquartzite
- 2% Rock fragments - micaceous and chloritic.
- 2% Feldspar

Varietal Minerals:

5% Glauconite

1% Accessory Minerals:

Anatase

Zircon

Garnet

Siderite

Classification: Glauconitic orthoquartzite

Thin Section number - 4072

Location - Carcajou River Section 623.5'-624'

Formation - Imperial Formation

Description:

Color - fresh surface - medium light gray to greenish gray.

Texture - clastic, fine sand, subangular to rounded, well sorted, oolitic in part, poorly indurated, fairly well cemented, poor porosity.

Essential Components:

- 25% Quartz - grains subangular to subrounded, generally subrounded, average size 0.1-0.15 mm., contacts rare, grains separated by calcite and hematite, hematite coatings abundant, inclusions common, irregular dusty or globular, occasional "bubble trains", 50% strained.
- 27% Chert and microquartzite - subrounded, hematite coatings common.
- 25% Oolitic hematite
- 18% Organic Material - (preserved as calcite, hematite and collophane), gastropods, echinoid plates.

Cement:

30% Calcite

Classification: Hematitic bioclastic arenite.

Thin Section number - 4074

Location - Carcajou River Section 558'-559'

Formation - Imperial Formation

Description:

Color - fresh surface - olive gray to medium gray.

Texture - biogenic limestone with bioclastic, quartzitic coarse silt to fine sand matrix, well indurated, well cemented, little porosity.

Essential Components:

- 7% Quartz - grains subangular to subrounded, average size 0.1 mm., contacts rare, overgrowths rare, inclusions common, irregular dusty to globular, 50% strained.
- 50% Carbonate Stromatoporoidal remains.
- 4% Carbonate Shell Material (exclusive of Stromatoporoids).

Varietal Minerals:

- 2% Carbonaceous material

Accessory Minerals:

Feldspar

Rock fragments

- 1% Hematite

Cement:

37% Calcite

Classification: Stromatoporoidal limestone

Thin Section number - 4077

Location - Carcajou River Section 352'-356'

Formation - Imperial Formation

Description:

Color - fresh surface - brownish gray.

Texture - clastic, subangular to subrounded, generally subangular, fairly well sorted, well indurated, poorly cemented, very slight porosity.

Essential Components:

- 50% Quartz - grains subangular to subrounded, generally subangular, average size 0.05-0.1 mm., contacts numerous but grains may be separated by cement, hematite coatings common, inclusions common, irregular dusty and globular, occasional "bubble trains", 50% strained.
- 5% Chert and Microquartzite
- 3% Feldspar
- 7% Rock fragments - micaceous and chloritic quartzite.

Varietal Minerals:

- 3% Mica (muscovite, biotite) and chlorite
- 15% Hematite

Matrix:

- 5% Micaceous and chloritic phyllosilicates.

Cement:

- 12% Calcite

Classification:

Hematitic lithic sandstone.

APPENDIX C

Location of Samples

I Samples for Thin Section Study

(a) Imperial River Section (IRS)

<u>Formation</u>	<u>Thin Section Number</u>	<u>Distance Below Highest Exposure (feet)</u>
Cretaceous (Sans Sault Formation?)	4067	0-9
	4066	130-145
		<u>Distance Below Top (feet)</u>
Imperial Formation	4065	490-528
	4064	837-838
	4063	912-913
	4062	928-938
	4061	1055-1088
	4060	1108-1128
	4059	1618-1668
	4058	1668-1718

(b) Carcajou River Section (CJRS)

<u>Formation</u>	<u>Thin Section Number</u>	<u>Distance Below Top (feet)</u>
Imperial Formation	4079	80-88
	4078	60-210
	4077	352-356
	4076	436-443
	4075	507-545
	4074	558-559
	4073	582-583
	4072	623.5-624
	4071	673-680
	4070	797
	4069	847
	4068	952-972

(c) Redstone Tributary Section (RTS)

<u>Formation</u>	<u>Thin Section Number</u>	<u>Distance Below Top (feet)</u>
Imperial Formation	4087	614
	4086	660
	4085	720
	4084	880-883
	4083	958
	4082	1058
	4081	1158
	4080	1358

II Samples for Heavy Mineral Study

(a) Imperial River Section (IRS)

<u>Formation</u>	<u>Slide Number</u>	<u>Distance Below Highest Exposure (feet)</u>
Cretaceous (Sans Sault Formation?)	8	0-9
	7	130-145

		<u>Distance Below Top (feet)</u>
Imperial Formation	6	490-528
	5	858-828
	4	928-938
	3	1108-1128
	2	1618-1668
	1	1668-1718

(b) Carcajou River Section (CJRS)

<u>Formation</u>	<u>Slide Number</u>	<u>Distance Below Top (feet)</u>
Imperial Formation	17	80-88
	16	60-210
	15	352-356
	14	436-443
	13	507-545
	12	604-643
	11	673-680
	10	792-897
	9	952-972

(c) Redstone Tributary Section (RTS)

<u>Formation</u>	<u>Slide Number</u>	<u>Distance Below Top</u> (feet)
Imperial Formation	24	614
	23	660
	22	880-883
	21	958
	20	1058
	19	1158
	18	1358

III Samples for Clay Mineral Study

<u>Formation</u>	<u>Section</u>	<u>Distance Below Top</u> (feet)
Imperial Formation	CRS	0-75
	CRS	110
	CJRS	1062-1427
	IRS	1128-1168
	IRS	585-828
	IRS	0-6

IV Samples for Micropaleontological Study

(a) Imperial River Section (IRS)

<u>Formation</u>	<u>Distance Below Top</u> (feet)
Cretaceous, Sans Sault Formation?	56-130
Imperial Formation	0-6
	6-16
	16-338
	585-828
	1128-1168
	1618-1668
	1668-1718

(b) Canol Road Section (CRS)

<u>Formation</u>	<u>Distance Below Top</u> (feet)
Imperial Formation	110
Fort Creek Formation	0-75
	75-480

(c) Carcajou River Section (CJRS)

<u>Formation</u>	<u>Distance Below Top</u> (feet)
Imperial Formation	0-60 213-507 574-545 643-673 767-802 897-952 972-1017 1017-1062 1062-1427

(d) Redstone Tributary Section (RTS)

<u>Formation</u>	<u>Distance Below Top</u> (feet)
Imperial Formation	0-180

APPENDIX D

Description of Non-Opaque Heavy Minerals

Apatite

Apatite is present in all the Late Devonian samples except CJRS-9. Apatite was absent in the Cretaceous rocks studied. The apatite is all colorless and commonly contains black, irregular dusty or globular inclusions. The grains are commonly rounded to subrounded, elongated, and generally subhedral to anhedral, rarely euhedral. Solution cavities are common on many of the grains. A small percentage of the apatite grains may be first cycle but the large majority are believed to be second cycle.

Anatase and Leucoxene

Anatase and leucoxene are present in all samples both Late Devonian and Cretaceous. These are the dominant heavy minerals in the Late Devonian but are less abundant in the Cretaceous. The two minerals are described together because of their apparent close association even within a single grain. Tabular (basal) and simple pyramidal crystals of anatase are present but generally the mineral occurs in rounded structureless grains difficult to identify with certainty. These grains range from greenish-yellow to almost opaque in color with high birefringence. Occasional uniaxial negative figures can be obtained but more commonly the grains are too dark to give interference figures. Very rarely small crystals of brookite have been observed as overgrowths on anatase or leucoxene grains.

As these crystals are extremely rare they have been omitted from the statistical counts. Under reflected light anatase and leucoxene vary from white to yellowish white in color. No distinction could be made between the two minerals as grains exhibiting characteristics of both, in varying proportions, are present. Both of these minerals are formed from the alteration of titaniferous minerals, and within the Imperial formation they are probably derived in situ from the decomposition of ilmenite. The abundance of these minerals and the complete absence of ilmenite which is commonly present in a mineral suite of this nature, lend support to this theory.

Biotite and Chlorite

Biotite and chlorite are present in all samples, both Late Devonian and Cretaceous. However, they occur only in minor amounts in the Cretaceous. These two minerals are grouped together because distinction on the basis of optical properties observed when the grains lie on the basal cleavage is not considered entirely reliable. Biotite grains ranging in color from green to brownish green are present in varying amounts throughout the Late Devonian samples. Material referred to as chlorite is much more abundant in the samples than biotite. These grains are usually some shade of green, but may have brownish casts. Practically all grains observed in the heavy mineral slides are rounded, subrounded, or sub-angular with little crystal shape exhibited but grains exhibiting well defined crystal shape have been observed in thin sections.

Irregular dusty or, less commonly, globular inclusions are commonly present. Some of these grains may be bleached or otherwise altered biotite.

Collophane

Collophane is found sporadically throughout both Late Devonian and Cretaceous samples. It is never very abundant but can be detected in varying amounts in most of the samples. The material is brown to yellowish brown in color and is isotropic between crossed nicols. The grains may show organic structure or more commonly may contain carbonaceous particles. The material has been observed in thin section as a replacement of bone, preserving both the Haversian canals and lacunae of the original bone. The majority of these grains are rounded but subangular to angular grains are present.

Garnet

The Imperial formation was found to be completely devoid of garnet, while in the Cretaceous it is the dominant heavy mineral. The garnet of the Cretaceous varies in color from colorless to pink. The garnet is angular and exhibits no indication of any abrasion. It is similar to garnet described by Milner (1952) as "etched".

Muscovite

Muscovite is present in all Late Devonian samples but is absent in the Cretaceous. The grains are generally colorless but may be pale green. Practically all grains observed in the heavy

mineral slides are rounded to subrounded and very rarely is crystal shape exhibited but grains exhibiting well defined crystal shape have been observed in thin sections. Inclusions are not common in these grains but irregular globular or dusty inclusions do occur.

Rutile

Rutile is present in both Late Devonian and Cretaceous strata. It is present in all Late Devonian samples except IRS-6. Two varieties based on color have been identified from rocks of both ages. One variety is moderate yellow (5Y7/6)* while the other is moderate brown (5YR4/4 to 5YR3/4). One variety may be present while the other is absent but more commonly they occur together in the same sample. The yellow variety is more common than the brown variety in total numbers. Both varieties are rounded, subrounded, or subangular and are generally subhedral, occasionally euhedral or anhedral. Striations are commonly present and occasional "knee" twins occur. The brown rutile commonly shows marked pleochroism while the yellow variety shows this characteristic only slightly. Solution "pits" are common on both varieties, while inclusions, although not common, are usually the irregular globular type. The minerals is believed to be entirely detrital in origin.

Siderite

Siderite is present in all samples of the Imperial River section, both Late Devonian and Cretaceous, but is absent in many of the Carcajou River section samples. The grains are light brown

* Color terminology - G.S.A. Rock Color Chart (1951)

(5YR5/6) in color and generally occur as spherulites or slightly elliptical grains. This material has been observed in thin sections replacing organic shell material. The erratic distribution and form of this mineral indicates that it is probably authigenic in origin.

Sphalerite

Sphalerite is present in some of the Late Devonian samples but is absent in the Cretaceous. The mineral is present in all the samples of the Imperial River section except IRS-6 and 7, but is present only sporadically in the Carcajou River section samples. Color is variable with variations of brown, yellow and green. The mineral is characterized by its color, isotropism and its high index (2.37). Grains are usually rounded but occasionally are well rounded or subangular. Inclusions when present are the irregular globular type. Sphalerite may be derived from veins, irregular ore bodies in limestones or as the result of organic decomposition. The subrounded to rounded nature of these grains indicates a detrital origin from reworked sediments.

Spinel

Spinel is present in all samples of both Cretaceous and Late Devonian age except IRS-6 and CJRS-17. The spinel present is the dark reddish brown (10R3/4) variety picotite. The mineral is characterized by its color, high index of refraction (1.718), isotropism and conchoidal fracture. The mineral rarely has inclusions and is generally subangular to subrounded. Spinel would

probably exhibit much more crystal shape as first cycle grains than that shown by the spinel present in the Imperial formation.

Tourmaline

Tourmaline is present in all samples of both Late Devonian and Cretaceous age. Two varieties, dusky yellowish green (10GY3/2) and moderate yellowish brown (10YR5/4), have been recognized. Colors given are those shown in the position of maximum absorption. The blue variety (indicolite) was also noted but as it occurs in such minute quantities (2 grains in 13 slides) it has been omitted from the statistical counts. In total numbers the green tourmalines are more common than the brown grains. Both varieties are similar in that they are subrounded to rounded, subhedral to anhedral, rarely euhedral, and contain abundant irregular dusty or globular inclusions. Opaque inclusions are present in practically all grains and are usually very common, occasionally extremely abundant. Most of these grains are probably multi-cycle although a few may be first cycle.

Zircon

Colorless zircon is present in every sample of both Late Devonian and Cretaceous age. Pink zircons ranging from grayish pink (5R8/2) to moderate red (5R5/4) are found only rarely in the Late Devonian but are fairly common in the Cretaceous. The two varieties are identical in characteristics except for their color. The grains are commonly rounded, occasionally angular to subangular, and occasionally well rounded. They are usually anhedral to subhedral and

only rarely euhedral. Zoned zircons are not uncommon. Inclusions of the irregular globular liquid type are commonly present, but are not abundant. These grains are predominantly multi-cycle but may rarely be first cycle.

Description of Opaque Heavy Minerals

Hematite

Hematite occurs abundantly in only two samples from the Late Devonian, CJRS-15, CJRS-16. It is absent in the Cretaceous samples and occurs only in traces in Late Devonian samples, exclusive of the two previously mentioned. The mineral is opaque and occurs in irregular grains. It occurs as an authigenic cement filling the pores and interstices of the sandstones and as oolites or clastic grains.

Pyrite

Pyrite is absent in the Cretaceous samples and occurs only sporadically in the Late Devonian samples. The mineral is brassy yellow under reflected light and either massive or in aggregates of minute crystals. It is found commonly covering quartz grains, which indicates its authigenic nature.

APPENDIX E

Description of Plates

Plate 1

Photomicrographs of Spores

(All specimens photographed with reflected light.
White forms are the result of dusting with ammonium
chloride).

Genus Spencerisporites Chaloner, 1951

?Spencerisporites sp.

Figure 1: Proximal view; flattened in dorso-ventral direction; spherical spore body encircled at equator by a sub-triangular bladder?; strongly developed trilete rays and well developed marginal frill; moderately spinose on distal surface. Width 666 u, length 633 u, CRS-110; (x60).

Figure 2: Same specimen as fig. 1, unwhitened; (x60).

Figure 3: Proximal view; flattened in dorso-ventral direction; strongly developed trilete rays extending into the bladder? as folds; marginal frill destroyed. Width 387 u, length 375 u, CJRS-1017'-1062'; (x80).

Figure 4: Same specimen as fig. 3, unwhitened; (x80).

Genus Triletes (Bernie and Kidston) ex Zerndt, 1930

?Triletes sp.

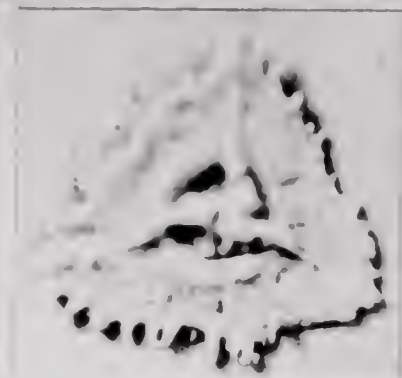
Figure 5: Proximal view; flattened in dorso-ventral direction; tri-radiate ridges over 3/4 of spore radius; spore coat very finely granulated; low arcuate ridge present. Width 400 u, length 425 u, CRS-110'; (x80).

Figure 6: Same specimen as fig. 5, whitened; (x80).

Figure 7: Proximal view; flattened in dorso-ventral direction; tri-radiate ridges extend 3/4 of spore radius; spore coat smooth to very finely granulated. Width 566 u, length 616 u, IRS-1668'-1718'; (x60).

Figure 8: Proximal view; flattened in dorso-ventral direction; tri-radiate ridges extend over 3/4 of the spore radius. Width 500 u, length 516 u, CRS-110'; (x60).

- Figure 9: Proximal view; flattened in dorso-ventral direction; tri-radiate ridges nearly as long as spore radius; spore coat smooth to very finely granulated. Width 466 u, length 500 u, IRS-1668'-1718'; (x60).
- Figure 10: Proximal view; flattened in dorso-ventral direction; tri-radiate ridges nearly as long as spore radius; spore coat smooth to very finely granulated. Width 337 u, length 375 u, CRS-110'; (x80).
- Figure 11: Proximal view; flattened in dorso-ventral direction; spore coat smooth to very finely granulated; distal surface unornamented. Width 600 u, length 600 u, CRS-110'; (x60).
- Figure 12: Same specimen as fig. 11, unwhitened; (x60).
- Figure 13: Proximal view; spore flattened in dorso-ventral direction; lobate expansions of spore coat developed at radial extremities; well developed arcuate ridge; spore coat smooth to very finely granulated; distal surface unornamented. Width 650 u, length 666 u, picture reversed in printing, CJRS-1017'-1062'; (x60).
- Figure 14: Same specimen as fig. 13, whitened; (x60).
- Figure 15: Proximal view; flattened in dorso-ventral direction; well developed trilete rays extending to equator; spore coat smooth to very finely granulated; distal surface unornamented. Width 262 u, length 262 u, picture reversed in printing, CJRS-1017'-1062'; (x80).
- Figure 16: Same specimen as fig. 15, whitened; (x80).
- Figure 17: Proximal view; flattened in dorso-ventral direction; tri-radiate ridges extend $\frac{3}{4}$ spore radius; spore coat smooth to very finely granulated; arcuate ridge present. Width 237 u, length 250 u, CRS-110'; (x80).
- Figure 18: Same specimen as fig. 17, whitened; (x80).
- Figure 19: Lateral view; flattened laterally; strongly spinose; spines up to 200 u long. Width 466 u, length 533 u, CJRS 1017'-1062'; (x60).
- Figure 20: Same specimen as fig. 19, unwhitened. Picture reversed in printing; (x60).
- Figure 21: Distal view; flattened in dorso-ventral direction; strongly spinose, spines up to 183 u. Greatest dimension (including ornamentation) 716 u, CRS-110'; (x60)
- Figure 22: Same specimen as fig. 21, unwhitened, picture reversed in printing; (x60).



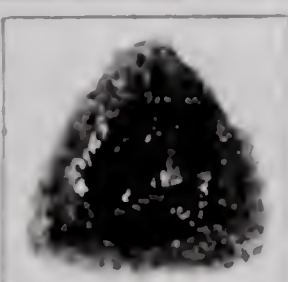
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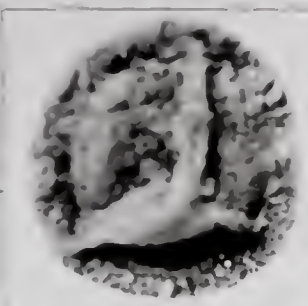
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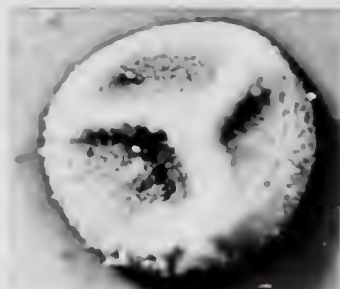
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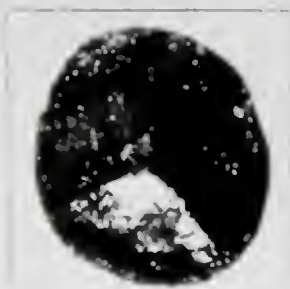
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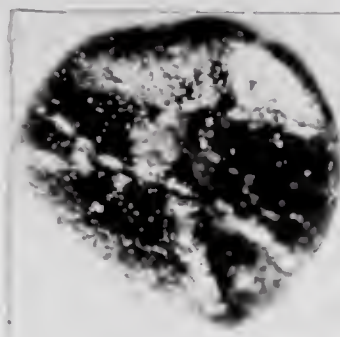
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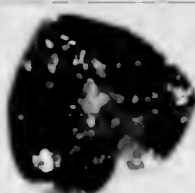
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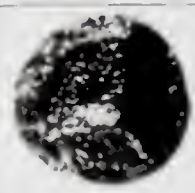
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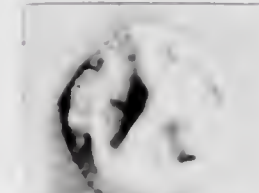
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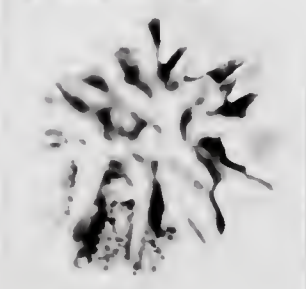
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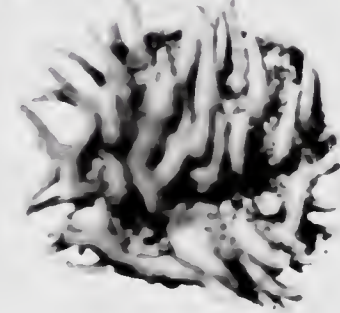
18.



19.



20.



21.



22.

Description of Plates

Plate 2

Photomicrographs of Spores

(All Specimens photographed with reflected light.
White forms are the result of dusting with ammonium
chloride).

Genus Triletes (Bennie and Kidston) ex. Zerndt, 1930

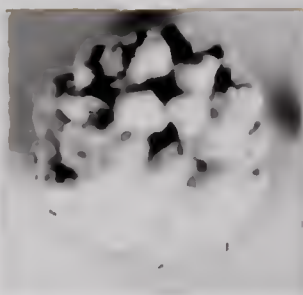
?Triletes sp.

- Figure 1: Lateral view; flattened laterally; strongly spinose, spines are short and broad. Greatest dimension (including ornamentation) 466 u, IRS-1668'-1718'; (x60).
- Figure 2: Same specimen as fig. 1, unwhitened; (x80).
- Figure 3: Slightly oblique compression, strongly spinose, spines up to 266 u long. Width (including ornamentation) 483 u, length (including ornamentation) 500 u, CRS-110'; (x60).
- Figure 4: Same specimen as fig. 3, unwhitened; (x80).
- Figure 5: Distal view, flattened in dorso-ventral direction, strongly spinose, spines up to 333 u long. Width 483 u, length 816 u, CRS-110'; (x60).
- Figure 6: Same specimen as fig. 5, whitened; (x60).
- Figure 7: Distal view, flattened in dorso-ventral direction, strongly spinose, spines up to 216 u. Width (including ornamentation) 450 u, length (including ornamentation) 533 u, CRS-110'; (x60).
- Figure 8: Distal view; spore flattened in dorso-ventral direction; strongly spinose; proximal surface poorly preserved; spines up to 166 u, but poorly preserved. Greatest diameter (including ornamentation) 533 u, CRS-110'; (x60).
- Figure 9: Same specimen as fig. 8, unwhitened; (x80).
- Figure 10: Distal view; flattened in dorso-ventral direction; strongly spinose on distal surface; proximal surface smooth to very finely granulated; spines up to 266 u, Width (including ornamentation) 616 u, length (including ornamentation) 833 u, CJRS-1017'-1062'; (x60).

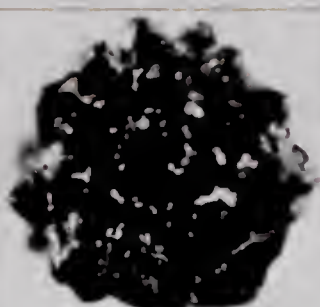
- Figure 11: Same specimen as fig. 10, proximal view; (x60).
- Figure 12: Distal view; flattened in dorso-ventral direction; strongly spinose on distal surface, spines up to 183 u long. Width (including ornamentation) 450 u, length (including ornamentation) 666 u, IRS-1668'-1718'; (x60).
- Figure 13: Distal view, flattened in dorso-ventral direction; strongly spinose on distal surface, spines up to 233 u long. Width (including ornamentation) 550 u, length (including ornamentation) 650 u, IRS-1668'-1718'; (x60).
- Figure 14: Lateral view; flattened laterally; distal surface strongly spinose, spines up to 166 u long. Width (including ornamentation) 616 u, length (including ornamentation) 533 u, CRS-110'; (x60).
- Figure 15: Proximal view; flattened in dorso-ventral direction; distal surface spinose, spines short, broad and tapering. Greatest diameter (including ornamentation) 425 u, CRS-110'; (x80).
- Figure 16: Proximal view; flattened in dorso-ventral direction; trilete rays strongly developed, extending to equatorial region of spore body; distal surface strongly spinose. Greatest diameter (including ornamentation) 400 u, CRS-110'; (x80).
- Figure 17: Same specimen as fig. 16, distal view; (x80).
- Figure 18: Distal view; flattened in dorso-ventral direction; strongly spinose on distal surface. Greatest diameter (including ornamentation) 412 u, IRS-1668'-1718'; (x80).

Genus undifferentiated

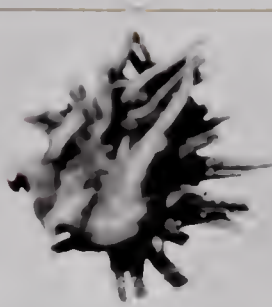
- Figure 19: Trilete rays not apparent; contains long tapering, bifurcating processes or spines over its entire area. Greatest diameter (including ornamentation) 312 u, CRS-110'; (x80).
- Figure 20: Same specimen as fig. 19, unwhitened; CRS-110'; (x80).
- Figure 21: Trilete rays are not apparent, long tapering spines abundant. Greatest diameter (including ornamentation) 175 u, CRS-110'; (x80).
- Figure 22: Spore similar to fig. 21. Greatest diameter (including ornamentation) 162 u, CRS-110'; (x80).



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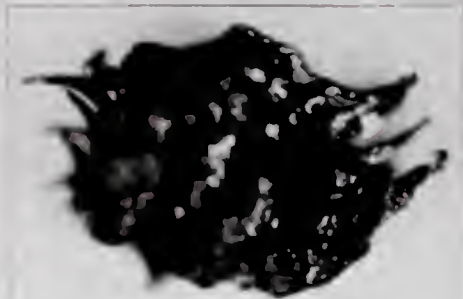
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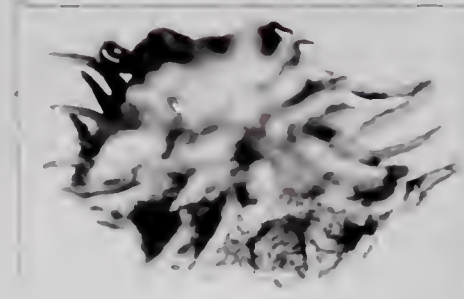
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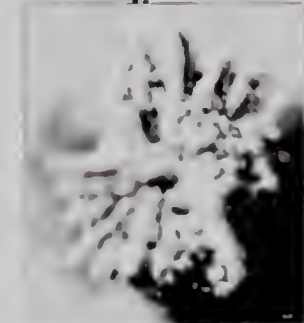
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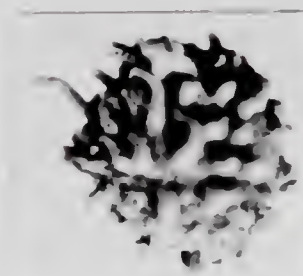
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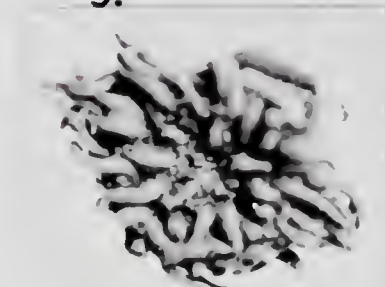
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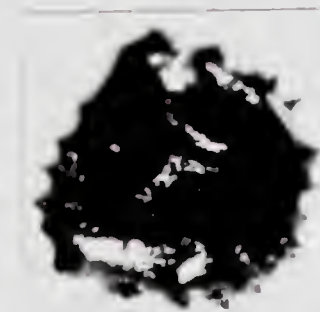
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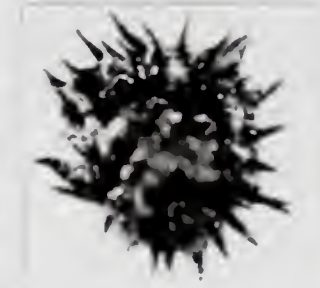
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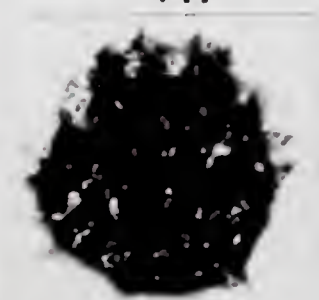
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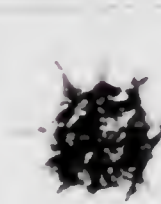
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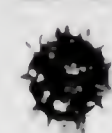
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Description of Plates

Plate 3

Photomicrographs of Scolecodonts

(All specimens photographed with reflected light.
White forms are the result of dusting with ammonium
chloride. All specimens are from CJRS-0'-60').

Genus Arabellites Hinde, 1879

?Arabellites sp.

- Figure 1: Maxilla I, left jaw, under side, strongly developed anterior hook. Denticulate inner margin, teeth inclined posteriorly. Obliquely truncate posterior end. Greatest length 0.75 mm.; (x60).
- Figure 2: Same specimen as fig. 1, upper side; (x60).
- Figure 3: Same specimen as figs. 1, 2, whitened, upper side; (x60).
- Figure 4: Maxilla II, left jaw, under side, sickle-shaped jaw, deep bight, prominent shank, teeth inclined posteriorly. Greatest length 0.78 mm.; (x60).
- Figure 5: Same specimen as fig. 4, unwhitened, under side; (x60).
- Figure 6: Maxilla I, right jaw?, under side?, strongly developed anterior hook. Denticulate inner margin. Posterior end missing. Greatest length 0.62 mm.; (x80).
- Figure 7: Same specimen as fig. 6, unwhitened, upper side?; (x80).
- Figure 8: Same specimen as figs. 6, 7, under side; (x80).
- Figure 9: Maxilla II, right jaw, upper side, sickle-shaped jaw, deep bight, prominent shank, teeth inclined posteriorly. Greatest length 0.70 mm.; (x60).
- Figure 10: Same specimen as fig. 9, unwhitened; under side; (x60).
- Figure 11: Same specimen as figs. 9, 10, under side; (x60).
- Figure 12: Maxilla I; right jaw, under side; anterior missing; denticulate inner margin; obliquely truncated posterior end. Greatest length 0.95 mm.; (x60).
- Figure 13: Same specimen as fig. 12, upper side; (x60).

Figure 14: Same specimen as figs. 11, 12, upper side; (x60).

Genus Leodicites Eller, 1940

?Leodicites sp.

Figure 15: Maxilla II, left jaw, upper side, shallow bight, pointed curved shank, teeth inclined posteriorly. Greatest length 0.75 mm.; (x60).

Figure 16: Same specimen as fig. 15, side view; (x60).

Figure 17: Same specimen as figs. 14, 15, under side; (x60).



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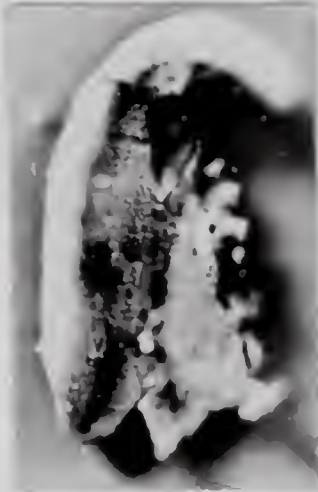
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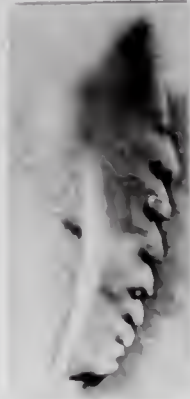
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Description of Plates

Plate 4

Photomicrographs of Scolecodonts

(All specimens photographed with reflected light.
White forms are the result of dusting with ammonium
chloride. All specimens are from CJRS-0'-60').

Genus Nereidavus Grinnell, 1877

?Nereidavus sp.

Figure 1: Maxilla I, left jaw?, upper side, denticulate ridge
bearing very small denticles does not show plainly.
Greatest length 0.92 mm.; (x60).

Figure 2: Same specimen as fig. 1, under side; (x60).

Genus Arabellites Hinde, 1879

?Arabellites sp.

Figure 3: Maxilla I, right jaw, under side. Greatest length
1.02 mm.; (x60).

Figure 4: Same specimen as fig. 3, whitened, under side; (x60).

Figure 5: Same specimen as figs. 3, 4, upper side; (x60).

Genus Lumbriconereites Ehlers, 1868

?Lumbriconereites sp.

Figure 6: Maxilla I or II, left jaw?, side view. Greatest
length 0.45 mm.; (x60).

Figure 7: Same specimen as fig. 6, whitened, side view; (x80).

Genus Eunicites Ehlers, 1868

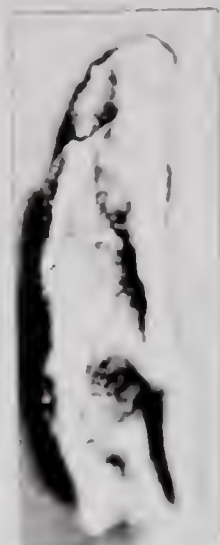
?Eunicites sp.

Figure 8: Maxilla III? or IV?, left jaw?, upper side. Greatest
length 0.55 mm.; (x80).

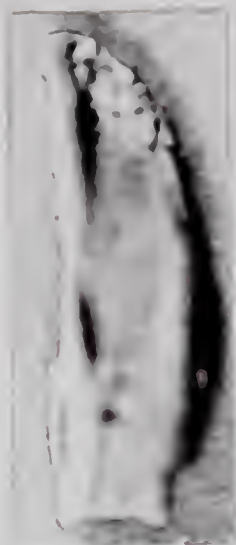
Figure 9: Same specimen as fig. 8, whitened, upper side; (x80).

Figure 10: Same specimen as figs. 8, 9, under side; (x80).

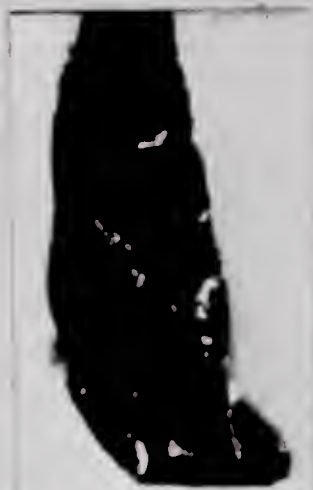
Figure 11: Maxilla III? or IV?, left jaw?, under side. Greatest
length 0.30 mm.; (x80).



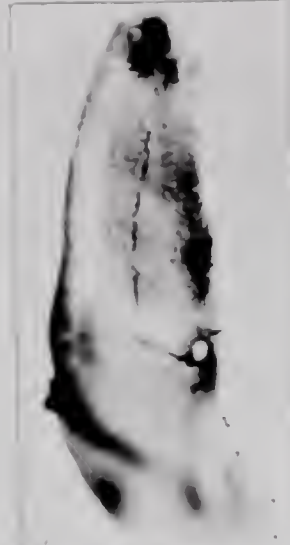
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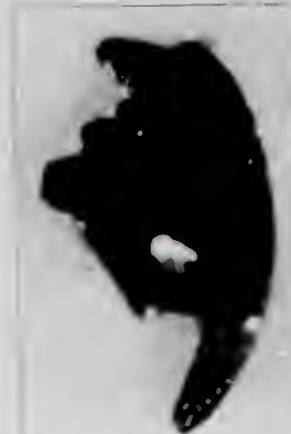
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Description of Plates

Plate 5

Photomicrographs of Heavy Minerals

- Figure 1: Zircon - IRS-4 - subrounded, zoned, colorless, subhedral, (x360).
- Figure 2: Zircon - IRS-1 - rounded, colorless, subhedral, (x360).
- Figure 3: Zircon - IRS-2 - rounded, zoned, colorless, subhedral, (x360).
- Figure 4: Zircon - IRS-2 - angular, colorless, euhedral, (x360).
- Figure 5: Zircon - IRS-4 - well rounded, pink, anhedral, (x360).
- Figure 6: Zircon - IRS-5 - rounded, colorless, subhedral, (x360).
- Figure 7: Rutile - IRS-2 - rounded, brown, subhedral, numerous solution pits, (x360).
- Figure 8: Rutile - IRS-1 - rounded, yellow, knee twin, subhedral, (x360).
- Figure 9: Rutile - IRS-4 - subrounded, yellow, subhedral, (x360).
- Figure 10: Rutile - IRS-4 - subrounded, yellow, anhedral, (x360).
- Figure 11: Rutile - IRS-5 - rounded, brown, anhedral, (x360).
- Figure 12: Apatite - IRS-1 - rounded, colorless, subhedral, dusty inclusions, (x360).
- Figure 13: Apatite - IRS-1 - rounded, colorless, subhedral, dusty inclusions, (x360).
- Figure 14: Apatite - IRS-4 - subrounded, colorless, anhedral, dusty inclusions, one globular inclusion, (x360).
- Figure 15: Apatite - IRS-1 - rounded, colorless, anhedral, dusty inclusions, (x360).
- Figure 16: Apatite - IRS-1 - rounded, colorless, anhedral, strongly corroded, dusty inclusions, (x360).
- Figure 17: Apatite - IRS-2 - rounded, colorless, anhedral, dusty inclusions, (x360).

- Figure 18: Tourmaline - IRS-4 - rounded, subhedral, dusty and globular inclusions, (x360).
- Figure 19: Tourmaline - IRS-1 - rounded, subhedral dusty and globular inclusions, (x360).
- Figure 20: Tourmaline - IRS-4 - subrounded, subhedral, dusty and globular inclusions, (x360).
- Figure 21: Tourmaline - IRS-4 - subrounded, subhedral, dusty inclusions, (x360).
- Figure 22: Tourmaline - IRS-1 - subrounded, anhedral, dusty inclusion, (x360).
- Figure 23: Anatase - IRS-4 - angular, euhedral, tabular (basal) grain, (x360).
- Figure 24: Anatase and Leucoxene(?) - IRS-4 - rounded, anhedral, (x360).
- Figure 25: Anatase and Leucoxene(?) - IRS-4 - rounded, anhedral, (x360).
- Figure 26: Anatase and Leucoxene(?) - IRS-2 - subrounded, subhedral, (x360).
- Figure 27: Anatase and Leucoxene(?) - IRS-2 - angular, euhedral, numerous euhedra on surface of large grain, (x360).



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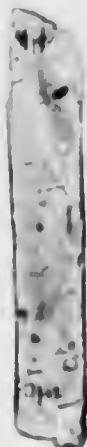
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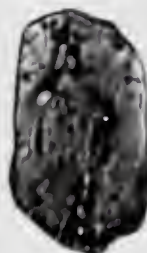
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Description of Plates

Plate 6

Photomicrographs of Heavy Minerals

- Figure 1: Spinel (Picotite) - IRS-2 - subrounded, brown, anhedral, (x360).
- Figure 2: Spinel (Picotite) - IRS-2, - subrounded, brown, anhedral, (x360).
- Figure 3: Spinel (Picotite) - IRS-4 - rounded, brown, anhedral, (x360).
- Figures 4,5: Siderite - IRS-1 - rounded, yellowish brown, spherulitic, aggregates, (x360).
- Figure 6: Sphalerite - IRS-2 - rounded, orange-yellow, anhedral, (x360).
- Figure 7: Sphalerite - IRS-2 - rounded, orange-yellow, anhedral, (x360).
- Figure 8: Sphalerite - IRS-2, rounded, orange-yellow, anhedral, (x360).
- Figure 9: Sphalerite - IRS-1 - rounded, green-yellow, anhedral, (x360).
- Figure 10: Sphalerite - IRS-2 - rounded, orange-yellow, anhedral, (x360).
- Figure 11: Zircon - IRS-7 (Cretaceous) - rounded, colorless, anhedral, (x360).
- Figure 12: Zircon - IRS-7 (Cretaceous) - rounded, colorless, zoned, anhedral, (x360).
- Figure 13: Zircon - IRS-7 (Cretaceous) - rounded, colorless, anhedral, (x360).
- Figure 14: Zircon - IRS-7 (Cretaceous) - rounded, colorless, anhedral, (x360).
- Figures 15-18: Garnet - IRS-7 (Cretaceous) - angular, colorless, etched, (x360).
- Figure 19: Tourmaline - IRS-7 (Cretaceous) - well rounded, anhedral, (x360).
- Figure 20: Collophane - IRS-4 - rounded, brown, (x360).



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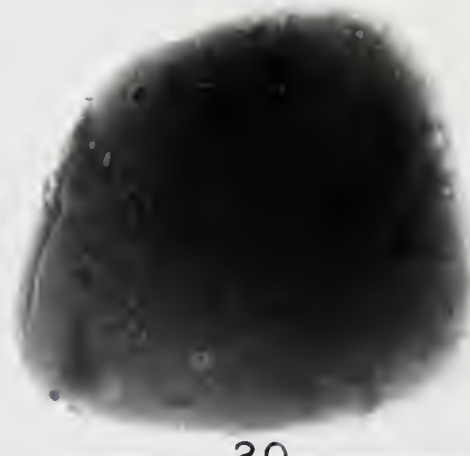
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Description of Plates

Plate 7

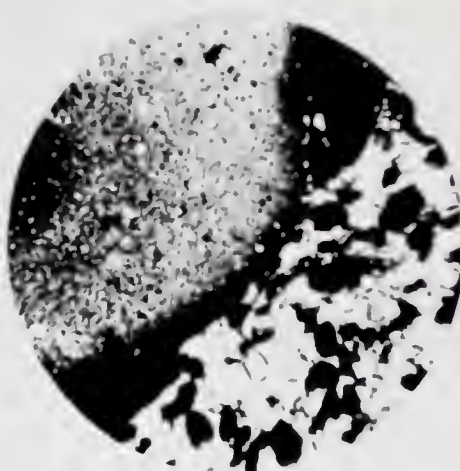
Thin-Section Photomicrographs

- Figure 1: IRS-4061 - quartzitic biocalcarenite; very coarse to fine bioclastic material, ostracod shell (far right), brachiopod shells (middle right), echinoid plate (far left); calcite (light), siderite (dark), quartz (white) in calcite cement; X-nicols, (x25).
- Figures 2-4: IRS-4063 - phosphatic hematitic bioclastic arenite.
Fig. 2 - large hematitic, pseudo-concretionary rock fragment (left half) surrounded by quartz (light) and oolitic or clastic hematite (dark) grains; plane polarized light, (x25).
Fig. 3 - large fish bone with collophane preservation; light grains are quartz; dark grains are oolitic or clastic hematite; plane polarized light, (x25).
Fig. 4 - large echinoid plate (upper left); light grains are quartz, dark grains are oolitic or clastic hematite; plane polarized light, (x25).
- Figures 5-6: IRS-4064 - lithic graywacke, very fine to fine sand.
Fig. 5 - light grains are quartz, chert and micro-quartzite; dark grains are rock fragments, mica, chlorite, matrix (micaceous and chloritic phyllosilicates); X-nicols, (x80).
Fig. 6 - large rounded argillaceous rock fragment (far left); large echinoid plate (top right); light grains (right half) are quartz, feldspar, chert and micro-quartzite; dark grains are rock fragments and matrix; plane polarized light, (x25).
- Figures 7-8: IRS-4065 - Lithic sandstone, fine sand, fairly well cemented.
Fig. 7 - light grains are quartz, chert and micro-quartzite, feldspar, calcite cement; dark grains are matrix (micaceous and chloritic phyllosilicates), rock fragments, siderite and hematite, mica and chlorite; plane polarized light, (x80).
Fig. 8 - same as fig. 7 with X-nicols; note well defined rounded chert grain (top of picture); X-nicols, (x80).

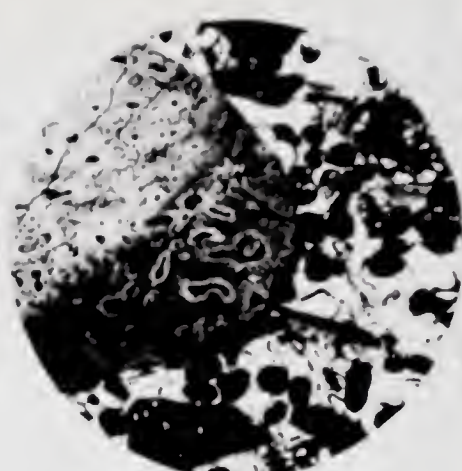
- Figures 9-10: IRS-4066 (Cretaceous) - glauconitic orthoquartzite, medium to fine sand, silica cement.
Fig. 9 - clean quartz grains showing crystal faces developed by overgrowths; X-nicols, (x80).
Fig. 10 - same as fig. 9 with plane polarized light; dark mineral is glauconite; light grains are quartz, chert and microquartzite; plane polarized light, (x80).
- Figure 11: IRS-4067 (Cretaceous) - lithic sandstone, fine sand, poorly cemented; light grains are quartz, chert and microquartzite, feldspar, calcite; dark grains are glauconite, siderite, matrix (micaceous and chloritic phyllosilicates); rock fragments; plane polarized light, (x80).
- Figure 12: CJRS-4068 - lithic sandstone, fine to very fine sand, poorly cemented; light grains are quartz, feldspar, chert and microquartzite; dark grains are matrix (micaceous and chloritic phyllosilicates), rock fragments, carbonaceous material, mica, chlorite; X-nicols, (x80).



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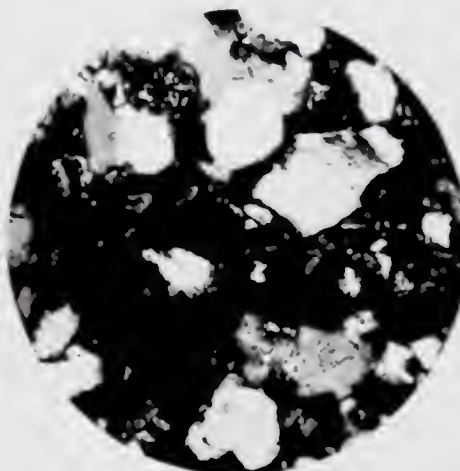
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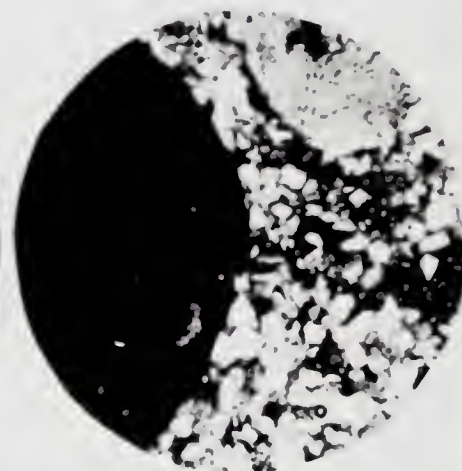
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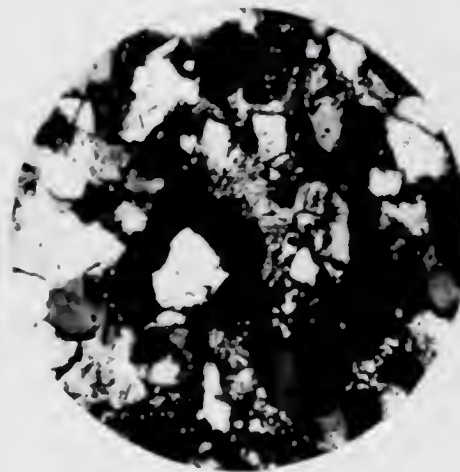
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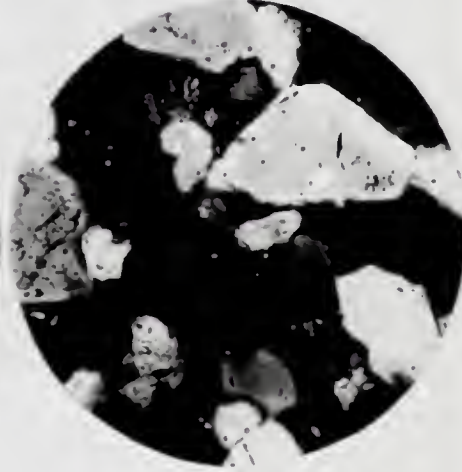
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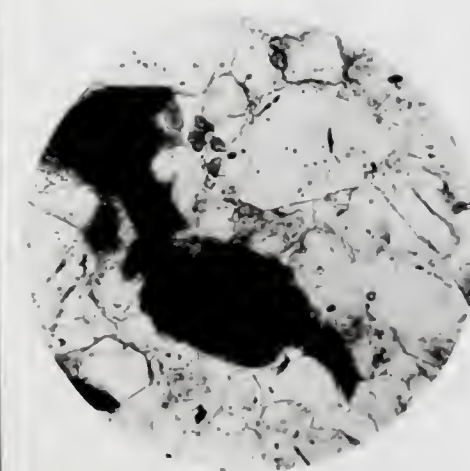
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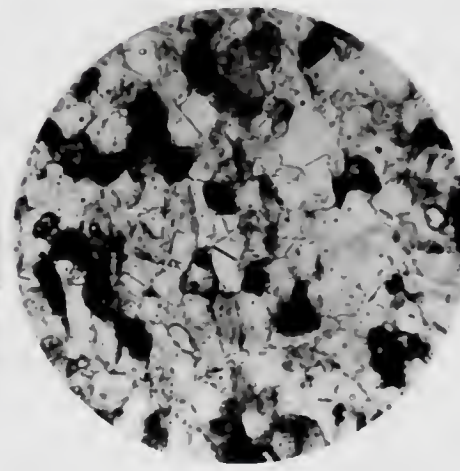
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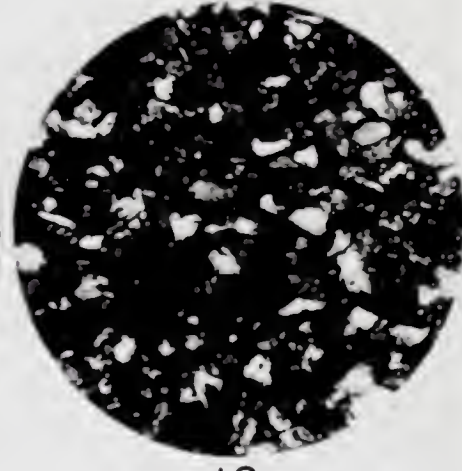
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Description of Plates

Plate 8

Thin-Section Photomicrographs

- Figures 1-2: CJRS-4070 - lithic sandstone, fine to very fine sand, poorly cemented.
Fig. 1 - large echinoid plate (left), X-nicols, (x80).
Fig. 2 - light grains are quartz, chert and micro-quartzite, feldspar, isolated patch of calcite . cement lower center; dark grains are matrix (micaceous and chloritic phyllosilicates), mica and chlorite, rock fragments, carbonaceous material, siderite; X-nicols, (x80).
- Figure 3: CJRS-4072 - hematitic bioclastic arenite, fine sand, fairly well cemented; large echinoid fragment (upper left); light grains are quartz, chert and micro-quartzite, calcite; dark mineral is oolitic hematite; X-nicols, (x80).
- Figures 4-5: CJRS-4074 - stromatoporoidal limestone.
Fig. 4 - stromatoporoidal remains, X-nicols, (x25).
Fig. 5 - mixture of stromatoporoidal remains and very fine quartz with calcite cement; plane polarized light, (x25).
- Figures 6-7: CJRS-4079 - hematitic lithic sandstone, medium to fine sand, poorly cemented.
Fig. 6 - light grains are quartz, chert and micro-quartzite, feldspar; dark grains are hematite, rock fragments; plane polarized light, (x80).
Fig. 7 - large brachiopod shell (upper center); light grains are quartz, chert and microquartzite, feldspar; dark grains are hematite, rock fragments; plane polarized light, (x80).
- Figures 8-9: RTS-4080 - lithic graywacke, very fine sand to coarse silt.
Fig. 8 - lamination of coarse silt (center) within very fine sand (top and bottom), (x25).
Fig. 9 - sharp contact between coarse silt (top) and very fine sand; plane polarized light, (x80).

THE HISTORY OF THE

REIGN OF

CHARLES THE FIRST

IN WHICH ARE CONTAINED THE MOST REMARKABLE PASSES OF HIS REIGN

FROM HIS FIRST COMING TO THE CROWN, UNTIL HIS DEATH, BY
JAMES HARRISON, ESQ. OF THE MIDDLE TEMPLE, ESQ. OF THE
COUNCIL OF THE KING, AND OF THE HOUSE OF COMMONS.

LONDON, Printed by J. Streater, at the Sign of the Gun, in
St. Dunstons Church, near St. Pauls, 1650.

THE HISTORY OF THE REIGN OF CHARLES THE FIRST, IN WHICH ARE CONTAINED THE MOST REMARKABLE PASSES OF HIS REIGN, FROM HIS FIRST COMING TO THE CROWN, UNTIL HIS DEATH, BY JAMES HARRISON, ESQ. OF THE MIDDLE TEMPLE, ESQ. OF THE COUNCIL OF THE KING, AND OF THE HOUSE OF COMMONS.

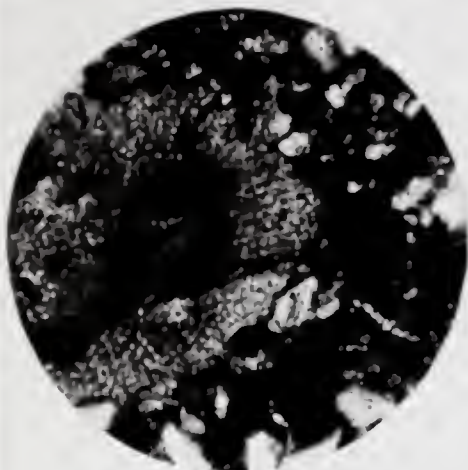
LONDON, Printed by J. Streater, at the Sign of the Gun, in St. Dunstons Church, near St. Pauls, 1650.

THE HISTORY OF THE REIGN OF CHARLES THE FIRST, IN WHICH ARE CONTAINED THE MOST REMARKABLE PASSES OF HIS REIGN, FROM HIS FIRST COMING TO THE CROWN, UNTIL HIS DEATH, BY JAMES HARRISON, ESQ. OF THE MIDDLE TEMPLE, ESQ. OF THE COUNCIL OF THE KING, AND OF THE HOUSE OF COMMONS.

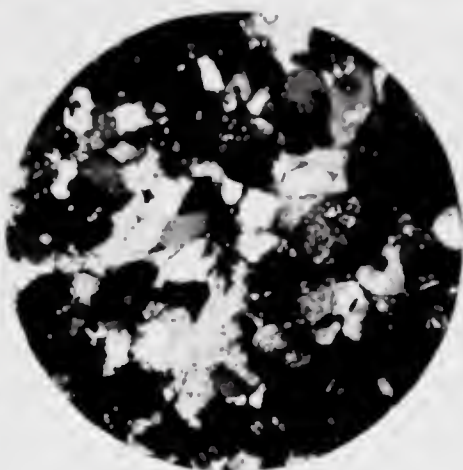
LONDON, Printed by J. Streater, at the Sign of the Gun, in St. Dunstons Church, near St. Pauls, 1650.

- Figure 10: RTS-4081 - lithic graywacke, very coarse silt to very fine sand; light grains are quartz, chert and micro-quartz, feldspar; dark material is matrix (micaceous and chloritic phyllosilicates), rock fragments, carbonaceous material; plane polarized light, (x80).
- Figure 11: RTS-4084 - lithic sandstone, fine sand, echinoid columnal (top left), brachiopod shells with argillaceous infillings (centre right and bottom); light grains are quartz, chert and microquartzite, feldspar; plane polarized light, (x25).
- Figure 12: RTS-4085 - ferruginous lithic sandstone, moderate to very fine sand, fairly well cemented; fragments of brachiopod shells (long, dark arcuate forms), light grains are quartz (hematite coatings common), chert and micro-quartzite, feldspar, calcite cement; dark grains are hematite, rock fragments, matrix (micaceous and chloritic phyllosilicates), mica, chlorite; plane polarized light, (x25).





1.



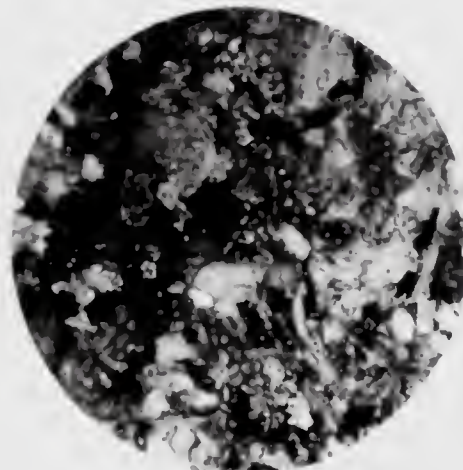
2.



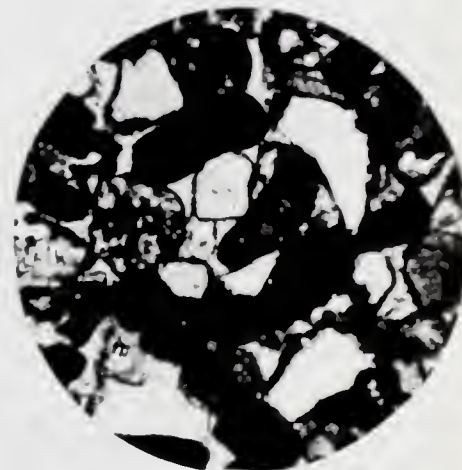
3.



4.



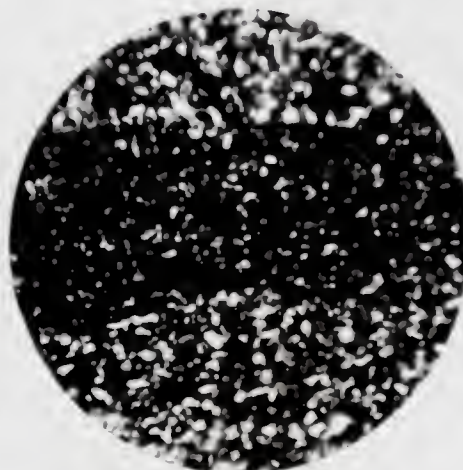
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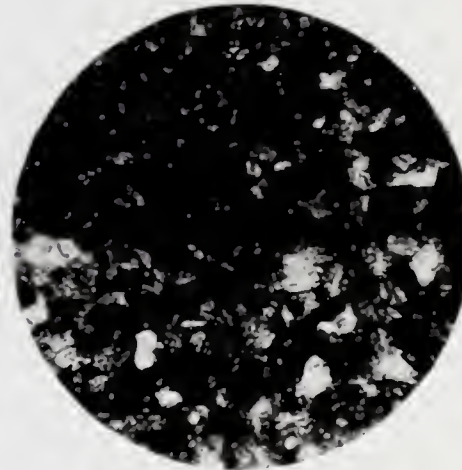
6.



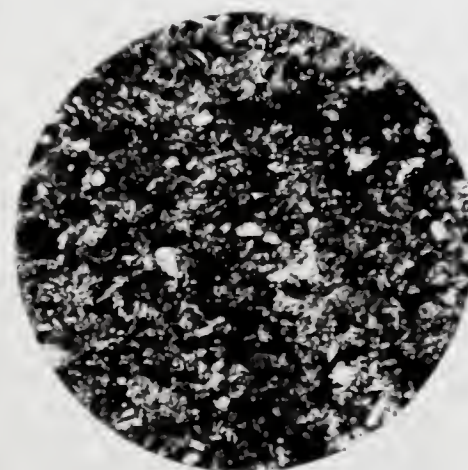
7.



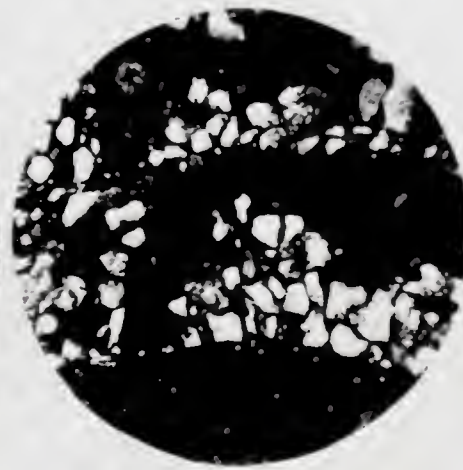
8.



9.



10.



11.



12.

Description of Plates

Plate 9

Photographs of Outcrops

- Figure 1: View of the middle sandstone-shale unit of the Imperial formation immediately southeast of CJRS on the Carcajou River (same location as frontispiece).
- Figures 2-4: Views of the middle sandstone-shale unit of Carcajou River section. Dark color of the upper sandstones is due to large quantity of hematite cement. All views are looking northeast from the Carcajou River.



1



2



3



4

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